# COLUMBIA RADIATION LABORATORY

## RESEARCH INVESTIGATION DIRECTED TOWARD EXTENDING THE USEFUL RANGE OF THE ELECTROMAGNETIC SPECTRUM

Eighth Quarterly Progress Report
September 16, 1961 through December 15, 1961

Contract: DA-36-039 SC-78330
DA Task No. 3A99-20-001-09

U. S. Army
Signal Research and Development Laboratory
Fort Monmouth, New Jersey

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December 15, 1961

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Columbia Radiation Laboratories, Columbia University
538 West 120th Street, New York 27, New York

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New experimental programs are described in microwave spectroscopy of molecules, the production of cryogenic magnets, and a rubidium "atomic clock". Final results are given for measurements of the $O^{17}H$ free radical.

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CU-12-61 SC-78330 Physics

Object of the research:
Physical research in fields in which microwave frequency techniques are employed; the development of microwave electronic and circuit devices.

The research reported in this document was made possible through support extended Columbia Radiation Laboratory, Columbia University, jointly by the Department of the Army (Signal Corps), the Department of the Navy (Office of Naval Research), and the Department of the Air Force (Air Force Office of Scientific Research) under the Signal Corps Contract DA-36-039 SC-78330.

DA Task No. 3A99-20-001-09
NR 372-101

Prepared by R. Novick

COLUMBIA UNIVERSITY
Division of Government Aided Research
New York 27, N.Y.

December 15, 1961

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The format of this issue has been revised.

The names of the authors are arranged alphabetically.

## ABSTRACT

A number of projects involving the optical detection of energy level crossings are described, including work on various isotopic species of zinc and cadmium. Results are given for the lifetimes of certain of these states. A new experiment is described for the measurement of the hyperfine structure of lithium ions. Several optical double-resonance studies are reported, including work on sodium and radioactive cadmium.

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## PUBLICATIONS AND LECTURES

### PUBLICATIONS:

I. D. Abella and C. H. Townes, "Mode Characteristics and Coherence in Optical Ruby Maser," Nature 192, 957 (1961).

L. C. Krisher and P. Thaddeus, "A Beam Maser Spectrometer," Rev. Sci. Instr. 32, 1083 (1961).

### LECTURES:

H. Z. Cummins spoke on "Some Scattering Experiments Using Optical Masers," at the M.I.T. Microwave Seminar, December 13, 1961.

Dr. M. N. McDermott lectured on the subject "Optical Double Resonance Studies of Radionuclei," at the Indiana University Physics Colloquium, on November 15, 1961.

B. Perry spoke (on behalf of Dr. M. N. McDermott) on "The Nuclear Spin of $Cd^{107}$," at the American Physical Society Meeting, in Chicago, Ill., November 24, 1961.

Dr. P. Thaddeus lectured on "Optical Detection of Level Crossings," at Bell Telephone Laboratories, Murray Hill, N.J., November 9, 1961.

# I. ATOMIC PHYSICS

## A. LIFETIME OF THE METASTABLE STATE OF SINGLY IONIZED HELIUM*

(L. Gampel, M. Lipeles, R. Novick)

This is an experiment to measure the lifetime of the 2S metastable state of singly ionized helium by a time-of-flight method.

The apparatus consists of a thirty-three foot long, eight inch diameter, stainless steel, bakeable vacuum tube. The tube is divided into three, separately pumped, chambers by baffle plates with small diameter apertures through which the ion beam may pass. The first chamber contains the ion source through which helium gas is passed at a pressure of $2 \times 10^{-5}$ mm Hg (air equivalent) and bombarded by 450 volt electrons to give a beam of helium ions of which about 1% are in the metastable state. The second or intermediate chamber, primarily for vacuum separation, contains a microwave quenching cavity and operates at a pressure of $5 \times 10^{-7}$ mm Hg (air equivalent). The third chamber is a thirty foot long drift tube containing a movable detector and operates at a pressure of $5 \times 10^{-9}$ mm Hg (air equivalent). The ion beam is constrained by an axial magnetic field to travel down the axis of the drift tube at a given velocity. The lifetime will be determined from the observed decay of the metastable signal.

We stated in the last quarterly report that the intensity of the ion beam was reduced by a factor of ten when the beam was focussed by lens # $2^{(1)}$ to pass through the .090 inch diameter hole between the intermediate chamber and the drift tube. After carefully studying the system we found that a .110 inch diameter hole reduced the intensity by only a factor of two and still gave the necessary vacuum separation.

Another problem arose from the fact that the detector is sensitive to both the ground and metastable state ions. As the signals are approximately in the ratio 750:1, shot noise from the ground state ions is comparable to the metastable signal unless we employ narrow band detection. In Fig. 1 we show a preamplifier circuit that feeds into a narrow band amplifier. This combination gives a signal-to-noise ratio of better than 30:1 in the metastable signal.

The complete vacuum envelope, comprising intermediate and source chamber, and drift tube was assembled with metal gaskets. A

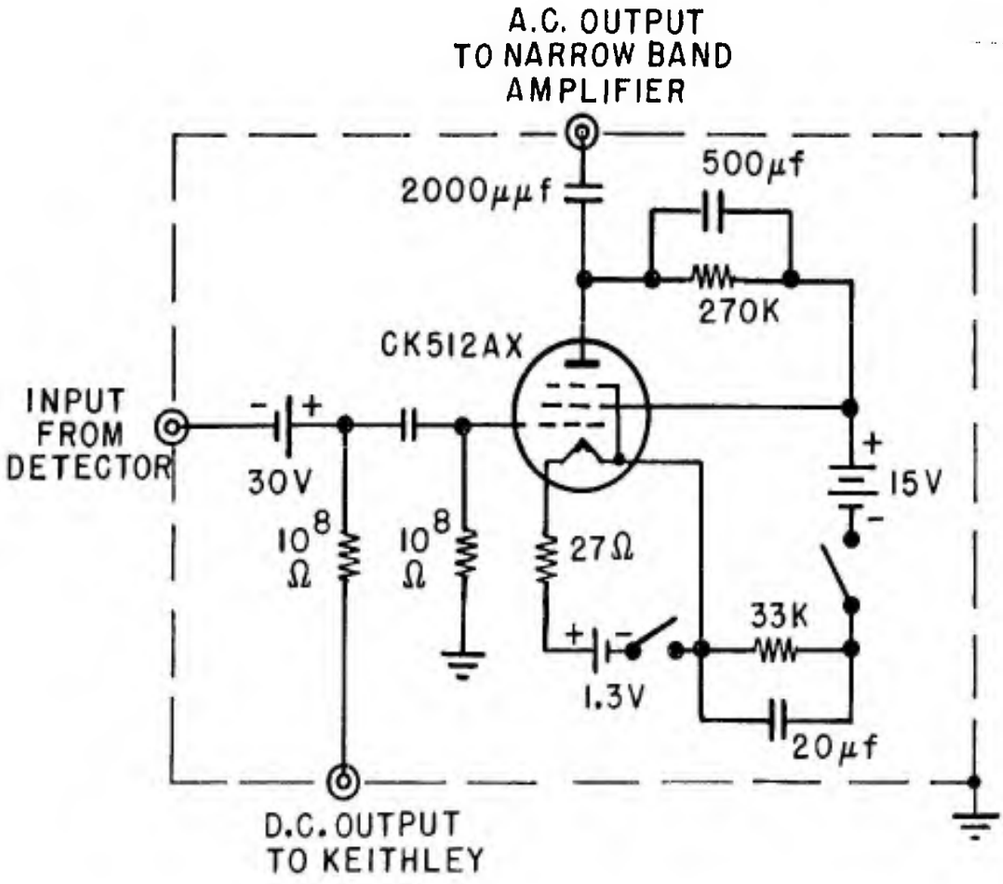


FIGURE 1. Detector preamplifier circuit.

pressure lower than $10^{-7}$ mm Hg was realized in all chambers.

Both ground state and metastable state ions were detected over the full length of the apparatus. Further studies will be made to measure the metastable decay, and determine the lifetime.

Prof. S. Devons has suggested that we perform a coincidence experiment to directly verify the two quantum nature of radiation resulting from the decay of the metastable helium ion. Suitable counting apparatus is being assembled for this purpose.

Program for the next interval:

(1) More data will be taken with the present apparatus.

(2) The tube will be baked out in an attempt to achieve a lower pressure and also eliminate the diffusion pump oil which is

contaminating the ion source. Further data will then be taken.

(3) Investigation of the ion beam trajectory in the axial magnetic field will be continued in order to determine space charge and scalloping effects.

(4) Design and study of the apparatus for the proposed experiment on the double quantum decay will continue.

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*This research was also supported by the Air Force Office of Scientific Research under Contract AF 49(638)-996.

1. CRL Quarterly Report, Sept. 15, 1961, Fig. 21, p. 39.

2. G. Breit and E. Teller, Astrophys. J. 91, 215 (1940).

## B. OPTICAL DETECTION OF LEVEL CROSSINGS

### 1. Optical Detection of Level Crossings of the Stable Isotope $Zn^{67}$*

(A. Landman, R. Novick, P. Thaddeus)

The experiment on the optical detection of level crossings of $Zn^{67}$, which has a nuclear spin of 5/2, has been continued and three crossings of interest have been observed so far. The problem of the design of a lamp has been solved (cf. Fig. 2) by encasing the cylindrical bulb used previously in a quartz vacuum jacket to maintain the necessary high temperature for the discharge, while keeping the exciting rf voltage down to a relatively low value. This procedure has prolonged the lifetime of the lamp and has produced an intense, stable beam of light.

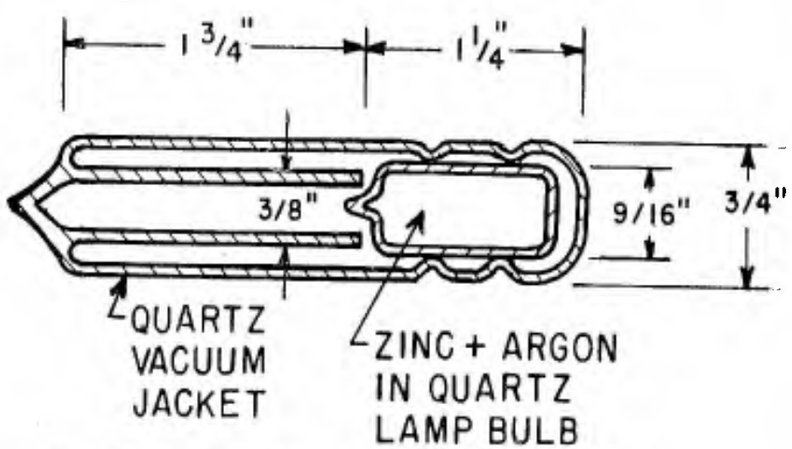


FIGURE 2. Zinc lamp bulb and vacuum jacket.

A new, isotopically enriched sample of $Zn^{67}$ for use in the scattering cell has proved satisfactory provided that great care is used in its preparation. The production of such a cell is more difficult than the production of a cell using ordinary zinc, because the scarcity of the enriched isotope does not permit vacuum distillation to be carried out prior to the transfer of the zinc to the cell. However, the signal is far stronger with the enriched zinc sample which contains 92% $Zn^{67}$ (according to Oak Ridge) than with the naturally occurring zinc, which has only about 4% $Zn^{67}$.

A partial quenching of the zinc resonance scattering may occur in the scattering cell due to slight impurities, whose vapor pressure is comparable to that of zinc (we suspect possible traces of sodium or another alkali metal). A new shipment of the enriched isotope has been ordered and better results than those below are expected. Even now, though, the field value corresponding to the strongest resonance can be given to 2 parts in $10^5$.

The major crossing, occuring for the $(F, m_F) = (5/2, -5/2)$ and $(3/2, -1/2)$ hyperfine levels of the 4s 4p $^3P_1$ state, has been observed at 869.62 ±.02 gauss. Two other crossings in which different levels of $F = 3/2$ bend and cross have also been observed. The strongest appears at about 894.2 gauss. A new sweep unit is being constructed and complete results for the four crossings in the $^3P_1$ state, which involve differences of 2 in $m_F$, are expected in the next quarter. These results will enable us to give a value $g_J$ for zinc to an accuracy comparable with that for cadmium, and in addition will enable us to check the dipole and quadrupole hyperfine constants.

An interpretation of $g_J$ for Zn, including relativistic and diamagnetic corrections, is in progress and should be applicable to Cd and Hg as well.

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*This research was supported also by the Office of Scientific Research under Contract AF 49(638)-996.

## 2. Optical Detection of Level Crossing in the 5s 5p $^3P_1$ State of Radioactive $Cd^{109}$ *

(M. McDermott, P. Thaddeus)

Using the techniques which have been applied to the natural odd isotopes of cadmium, $Cd^{111}$ and $Cd^{113}$, and which have been described in the past three Quarterly Reports, four crossings of the Zeeman levels of the hyperfine structure of the 5s 5p $^3P_1$ state of $Cd^{109}$ have been detected by observing the change in intensity of the resonance flourescence of the 3261 Å intercombination line. This isotope has a nuclear spin I of 5/2 and a half-life of 470 days. It was produced by the reaction $Ag^{109}(p,n)Cd^{109}$ in the Pupin cyclotron.

The four crossings observed all differ in $m_F$ by 2, and can be observed without polarization of the incoming light. The magnetic field at which crossing was observed to occur, in units of the nuclear magnetic resonance frequency of protons in mineral oil, together with the low field assignment of the levels are: $|F,m_F\rangle = |7/2, 7/2\rangle$ and $|5/2, 3/2\rangle$ at 6986.995(6) kc/sec; $|5/2, 3/2\rangle$ and $|5/2, -1/2\rangle$ at 6177.49(6) kc/sec; $|5/2, 1/2\rangle$ and $|5/2, -3/2\rangle$ at 5593.84(16) kc/sec; and $|5/2, -1/2\rangle$ and $|5/2, -5/2\rangle$ at 5007.73(24) kc/sec.

The strongest observed crossing, that of the $|7/2, 7/2\rangle$ and $|5/2, 3/2\rangle$ levels, has a signal-to-noise ratio of at least 10:1 with broadband oscilloscope detection. The other crossings were progressively weaker, but all have a signal strength of at least 10:1 with phase sensitive detection having detector time constants of about 1 sec. The crossing fields are consistent with the hyperfine intervals determined by a double resonance experiment[1], and should permit a still more precise determination of the hyperfine coupling constants.

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*This research was supported also by the Air Force Office of Scientific Research under Contract AF 49(638) - 996.

1. M. N. McDermott and R. Novick, Bull. Am. Phys. Soc. 6, 142 (1961).

## C. COHERENCE TIME MEASUREMENTS IN OPTICAL DOUBLE RESONANCE *

(F. Byron, M. McDermott, R. Novick)

During the last quarter experiments using the optical double resonance technique in cadmium have continued and new data con-

cerning atomic properties have been obtained.

Lifetime measurements: Work on the even isotopes to determine the radiative lifetime and the collision self-broadening cross section has essentially been completed. We have previously suggested the expression[1]

$$\Delta_{1/2}(H_1 = 0, T) = \frac{1}{\pi\tau}(1 - \alpha x) + \frac{n\bar{v}\sigma}{\pi} + \frac{3\bar{v}}{2\pi D}$$

as a possible formula for the half-width of a Zeeman resonance as a function of temperature.

The first term is just the natural line-width as modified by Barrat[2], the second term results from Cd-Cd collisions and the third is a small correction due to wall collisions. The symbols in the expression are defined in reference (1). For an accurate determination of the radiative lifetime, the third term is of critical importance since n and x can be made negligibly small by going to temperatures below 160 °C. This expression was derived assuming a spherical resonance cell and uniform illumination over the cell volume. To test these assumptions we have made measurements on two bulbs of diameter 1.16 cm and 3.30 cm respectively. Using our previously reported value[1] of 131 kc for the true zero-field half- width, we would expect half-widths of 148 kc and 137 kc respectively, with the inclusion of wall collision effects. The measurements gave $\Delta_{1/2} = (147 \pm 2)$ kc and $\Delta_{1/2} = (137 \pm 1)$ kc for the two cases. The zero-field half-widths were obtained by plotting the square of the half-width as a function of the applied rf voltage. We expect a relationship given by[1]

$$\Delta^2_{1/2} = (1/\pi\sigma)^2 + \frac{29}{5\pi^2}(\gamma H_1)^2 = (1/\pi\sigma)^2 + \frac{29\gamma^2 k^2}{5\pi^2} V_{rf},$$

$$(H_1 = k V_{rf})$$

where $\tau$ is the natural radiative lifetime. The results for the two cases, fitted to a straight line by least squares, are shown together in Fig. 3. A similar measurement was made using a cylindrical bulb of roughly the same dimensions as our spherical cells (see Fig. 4), and in this case the zero-field half-width was found to be (139 ±2) kc. This agrees with the other results within the stated error, but suggests that

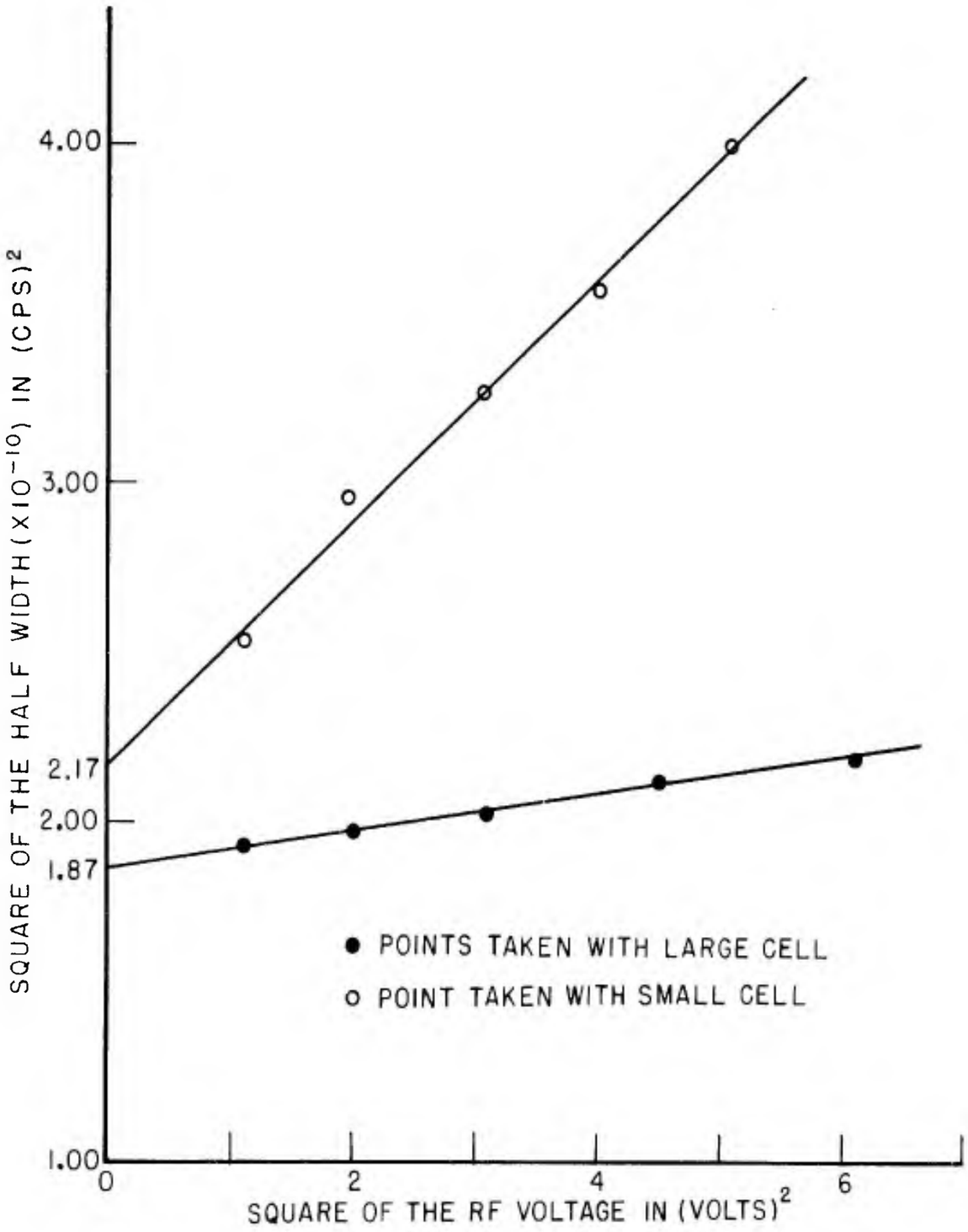



FIGURE 3. Resonance half-widths vs rf magnetic field for two different resonance cell sizes.

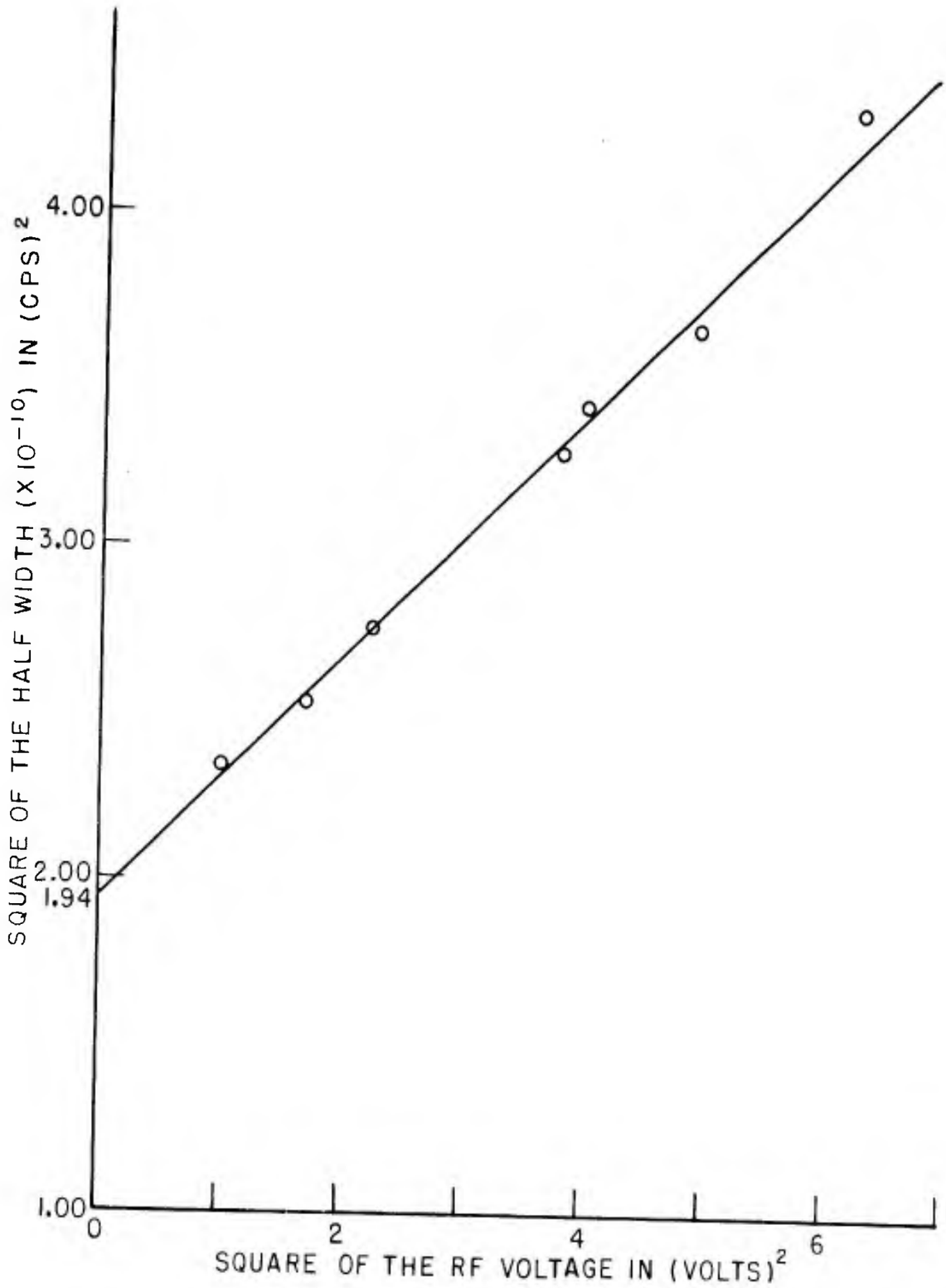



FIGURE 4. Resonance half-width vs rf magnetic field for cylindrical resonance cell.

there may be a small geometrical effect, i.e., that the result

$$\Delta_{1/2}\ (\text{wall collisions}) = \frac{3\,\bar{v}}{2\,\pi\,D}$$

holds exactly only for spherical cells.

One special precaution was taken before these data were accepted as final. The presence of foreign gas in the resonance cell is a potentially serious problem, and although we sealed our cells off from the vacuum system at pressures near $10^{-7}$ mm of Hg, there was still some concern about what happened to the cells when heated to operating temperature. To check on this, several cells were built with an ion gauge attached directly to the cell body. In this way it was possible to check the pressure directly, and the ion gauge also produced a favorable pumping action on the cell. When the cells were not baking, pressures as low as $5 \times 10^{-9}$ mm of Hg were seen, and at 150 °C (where most of our lifetime determinations were made) the pressure never exceeded what one would expect for pure cadmium in this temperature region. We feel, therefore, that foreign gas contamination was negligible.

In checking the simple additive approximation for $\Delta_{1/2}(H_1 = 0,T)$ the half-width was measured at low rf field and then extrapolated to zero-field. This was done at a large number of temperatures ranging from 430 °K to 620 °K. The results are shown in Fig. 5. The adequacy of the simple additive approximation in representing the experimental results is quite striking. It should be noted, however, that this curve was fit by adjusting two parameters, the cross section, $\underline{\sigma}$, and a quantity, $\underline{L}$, which appears in the expression for $\underline{x}^{(1,2)}$:

$$x = 1 - \exp\left\{-\frac{3\pi^2}{2}\,\frac{n\,L}{\tau\,\bar{v}\,k_o^3}\right\},$$

where $\underline{L}$ may be considered as the mean distance of an atom from the walls of the resonance cell. One would expect $\underline{L}$ to be of the order of magnitude of the radius of our spherical cell (about 1-1/2 cm). Our data was fit best by using $L = .85$ cm, in accordance with expectation. The parameters $\underline{\sigma}$ and $\underline{L}$ have their main importance in two separate regions (high and low temperatures, respectively), so the fitting process is correspondingly simplified. In the high temperature region the collision self-broadening term dominates, and we would expect to find $\Delta_{1/2}(T) = \text{Const.} + n\bar{v}\sigma/\pi$ in this region. Substituting for $\underline{n}$ and

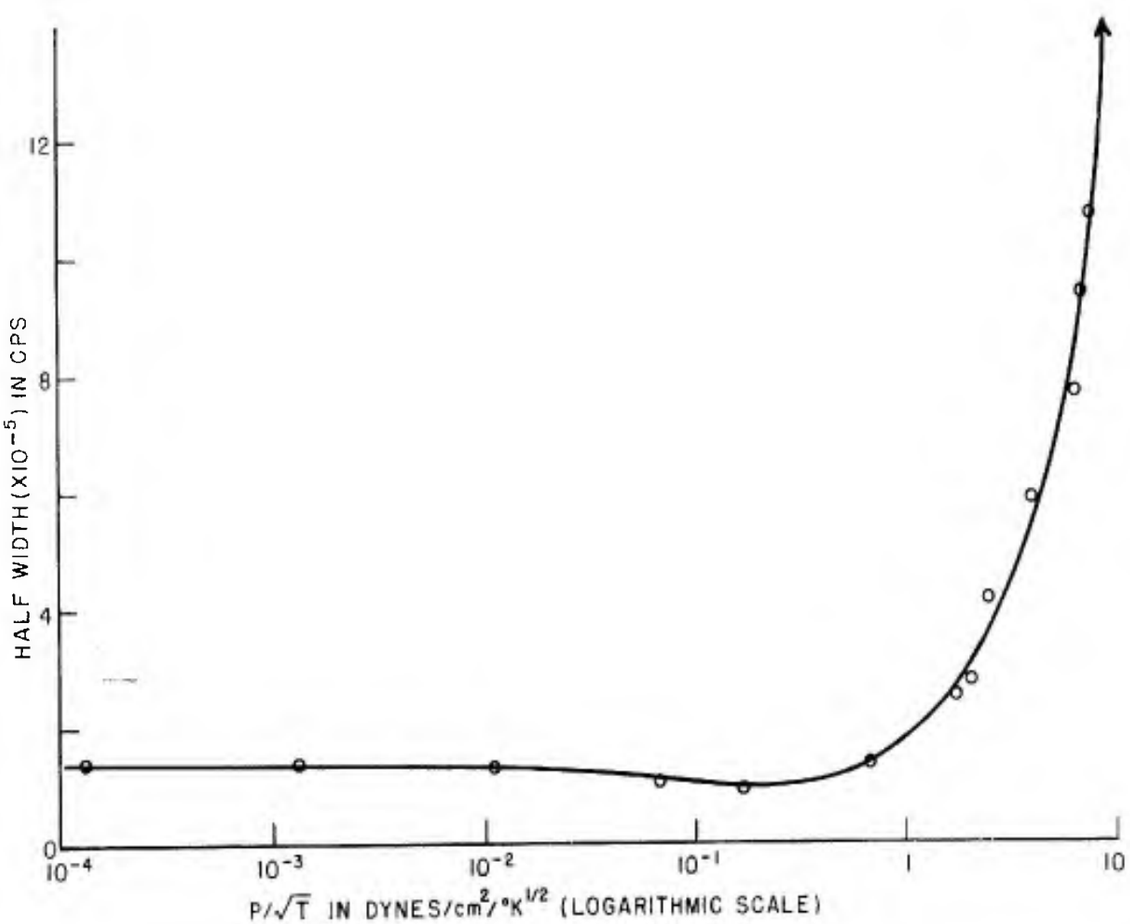



FIGURE 5. Resonance half-width as a function of temperature.

$\bar{v}$, we get

$$\Delta_{1/2}(T) \cong \text{Const.} + \frac{4\sigma}{\sqrt{\pi^3 k m}} \frac{P}{\sqrt{T}} .$$

Hence if we plot our data against $P/\sqrt{T}$ the slope of the curve in the high temperature region should give us an expression for the cross section due to collision broadening. The relevant portion of the curve is shown in Fig. 6. It gives a least-squares slope of $(1.26 \pm .13) \times 10^5$ which yields a cross section of $\sigma = (2.8 \pm .3) \times 10^{-14}$ cm$^2$. These data were taken over a period of several days and the temperature was raised and lowered twice, with points taken both as the temperature increased and decreased. The consistency of the data under these conditions would indicate that there were not effects present due to the driving of foreign gas from the walls. Our values of P were obtained by using empirical formulas quoted in Kubaschewski and Evans[3] who give for cadmium:

$$\log_{10} P = -\frac{A}{T} + B + C \log_{10} T + D T ,$$

where P is in mm of Hg. The constants are given by

$T < 594\ ^\circ$K: $A = 5908$, $B = 9.717$, $C = -0.232$, $D = -0.000284$

$T > 594\ ^\circ$K: $A = 5819$, $B = 12.287$, $C = -1.257$, $D = 0$.

Final evaluation of our results gives:

$$\Delta_{1/2}(H_1=0,\ T=0) = (1.31 \pm .02) \times 10^5 \text{ cps},$$

$$\tau = (2.43 \pm .04) \times 10^{-6} \text{ seconds},$$

$$\sigma = (2.8 \pm .3) \times 10^{-14} \text{ cm}^2 .$$

The lifetime measurements compare favorably with older results which gave values between 2.3 and $2.5 \times 10^{-6}$ seconds[4]. A recent measurement of $\tau$ by Butaux[5] has been brought to our attention[6]. He finds $\tau = (2.26 \pm .04) \times 10^{-6}$ seconds, i.e., a zero-field half-width of $(1.41 \pm .02) \times 10^5$ cps. He did not attempt to correct for wall collisions, but he used a cubic resonance cell, apparently about 3 cm on a side, which would suggest a 6 kc correction. However, the geometrical problem leaves this uncertain to about 2 kc, so a correction of $(.06 \pm .02) \times 10^5$ cps is probably reasonable. This would give a

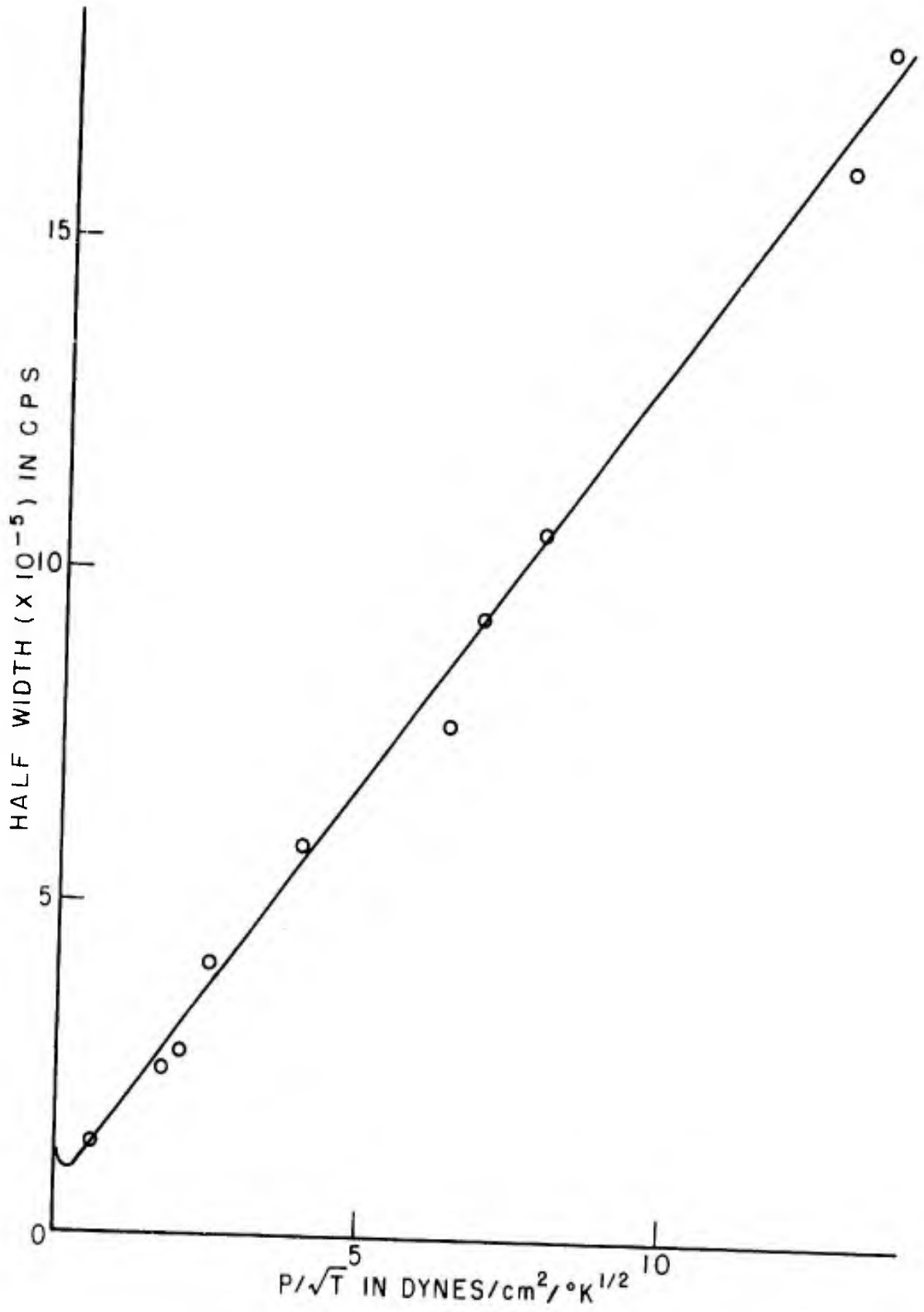



FIGURE 6. Resonance half-width as a function of temperature for high temperatures.

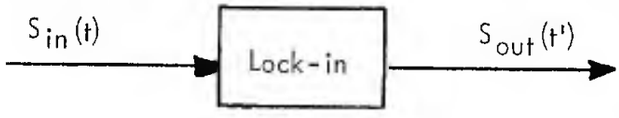
corrected value for Butaux's results of

$$\Delta_{1/2}(H_1=0,\ T=0) = (1.35 \pm .03) \times 10^5 \text{ cps}$$

which agrees to within the stated error with our results.

Our value for the cross section is large, indicative of resonance collisions between excited and ground state atoms. There are no data available for a good comparison, since Butaux's apparatus produced signals too feeble for accurate work in the high temperature region. However, his work suggests values of $\sigma$ of the order of magnitude of $10^{-14}$ cm$^2$, which are consistent with our result. Work is at present underway on a theoretical calculation of this cross section in an attempt to explain our number and to shed some light on the atomic processes involved.

Analysis of line distortion: An effect which must be accounted for in this work and in other optical double resonance experiments on our apparatus arises from the fact that we "sweep" the static magnetic field linearly with time in the neighborhood of resonance. The resulting signal is fed into a lock-in amplifier and sent out through an integrating circuit with time constant $\tau_{RC}$ ( 3 to 30 seconds in general). This will cause a distortion of the line shape. We have essentially




where the lock-in may be though to act in the following manner:

$$dS_{out}(t) = R(t-t')\,\frac{dS_{in}(t')}{dt'}\,dt',$$

$$S_{out}(t) = \int_{-\infty}^{\infty} R(t-t')\,\frac{dS_{in}(t')}{dt'}\,dt', \text{ where}$$

$$R(t-t') = \begin{cases} 0 \text{ for } t < t' \\ 1 - \exp\left[(t-t')/\tau_{RC}\right] \text{ for } t > t'. \end{cases}$$

Using the techniques of Fourier Theory, we have shown that

$$S_{out}(t) = S_{in}(t) - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{\omega\, \hat{S_{in}}(\omega)\, e^{i\omega t}}{\omega - (i/\tau_{RC})}\,d\omega.$$

$\hat{S}_{in}(\omega)$ is the standard notation for the Fourier transform. We assume now a Lorentz line shape of the form $S_{in}(t) = S\left[1 + (t-t_o)^2/R^2\right]^{-1}$, where $R = \Delta_{1/2}\ \tau_{sw}/2\ \Delta_t$, $\Delta_{1/2}$ is the half-width, $\tau_{sw}$ is the time interval during which the field is swept and $\Delta_t$ is the total interval over which we sweep. Making use of the smallness of the parameter $\beta$ given by $\beta = (\Delta_t\ \tau_{RC} / \Delta_{1/2}\ \tau_{sw})$ it is possible to obtain expansions for the various quantities of interest. The primary effect is to shift the line center in the direction of the sweep by

$$\omega_o' = \omega_o \pm \Delta_{1/2}\,\beta . \qquad (a)$$

(We denote the shifted quantities by a prime and include terms only through the first non-vanishing order.) The maximum intensity is changed by

$$\frac{S_{max} - S'_{max}}{S_{max}} = 4\beta^2$$

and, most important for us, the half-width is increased according to

$$\Delta'_{1/2} = \Delta_{1/2}\left[1 + 6\beta^2\right]. \qquad (b)$$

As might have been expected, the first mentioned shift is first order in $\beta$, while the others are second order. Equations (a) and (b) have been subjected to experimental verification by sweeping through some known Lorentzian line with $\Delta_t$ fixed and with various values of $\tau_{RC}/\tau_{sw}$. The measurements seemed to verify the theory to within 10%, which is all that can be expected given the nature of the approximation made. However, the importance of (b) is obvious. In our work on the $I = 0$ isotopes we measured half-widths of about .0070 amperes and used $\Delta_t \cong .020$ amps and $\tau_{RC}/\tau_{sw} = 1/100$. Hence, $\Delta'_{1/2} \cong 70 \times 10^{-4} + 0.3 \times 10^{-4}$ amps, which is a negligible correction. It should be noted that a $\tau_{RC}/\tau_{sw}$ ratio even as small as 1/60 would give a correction of about $1 \times 10^{-4}$ amps which is not desirable in such an experiment as ours.

Program for the next interval: In the next quarter we propose to work on the radiative lifetime and collision self-broadening in the odd cadmium isotopes. For theoretical reasons the last mentioned quantity is of particular interest, while the lifetime will provide a useful check on our even isotope results.

*This work was also supported in part by the Air Force Office of Scientific Research under AF-AFOSR-62-65.

1. CRL Quarterly Report, Sept. 15, 1961, p. 41.

2. J. P. Barrat, J. phys. radium 20, 1959.

3. Kubaschewski and Evans, Metallurgical Thermochemistry ( John Wiley and Sons, Inc., New York, 1956).

4. A. C. G. Mitchell and M. W. Zemansky, Resonance Radiation and Excited Atoms (Cambridge University Press, Cambridge,England, 1934).

5. Jean Butaux, Mesure de la Durée de Vie du Niveau $5\,^3P_1$ de l'Atome de Cadmium par la Methode de Double Résonance, Diplome d'Etudes Superiere, Paris, October, 1961.

6. J. Brossel, private communication.

## D. FINE STRUCTURE OF IONIZED LITHIUM*

(P. D. Feldman, R. Novick)

A new experiment is planned for the precision measurement of the fine structure of the short-lived n = 2 triplet-p state of singly ionized lithium.

The fine structure and the hyperfine structure of the $2\,^3P_{0,2,1}$ and $2\,^3S_1$ levels in $Li^{7+}$ and $Li^{6+}$ are shown in Fig. 7. The measurements on $Li^{7+}$ were done optically[1] and the fine structure intervals

$$^3P_0 \longrightarrow {}^3P_1 = 5.1_5 \text{ cm}^{-1} \ (\approx 174 \text{ kMc/sec})$$

and

$$^3P_1 \longrightarrow {}^3P_2 = -2.1_0 \text{ cm}^{-1} \ (\approx -70 \text{ kMc/sec})$$

were obtained. The hyperfine splitting of the less abundant stable isotope, $Li^{6+}$ is smaller than that for $Li^{7+}$ because of the large difference in nuclear g-value for the two isotopes ( $g_I (Li^{7+}) / g_I (Li^{6+}) = 2.64$), and hence has never been measured either optically or by rf spectroscopy. The 3P ⟶ 3S transition wavelength is 5484.7 Å, which conveniently permits optical detection of atoms decaying from the level we wish to observe. Because of the higher Z of lithium, the fine

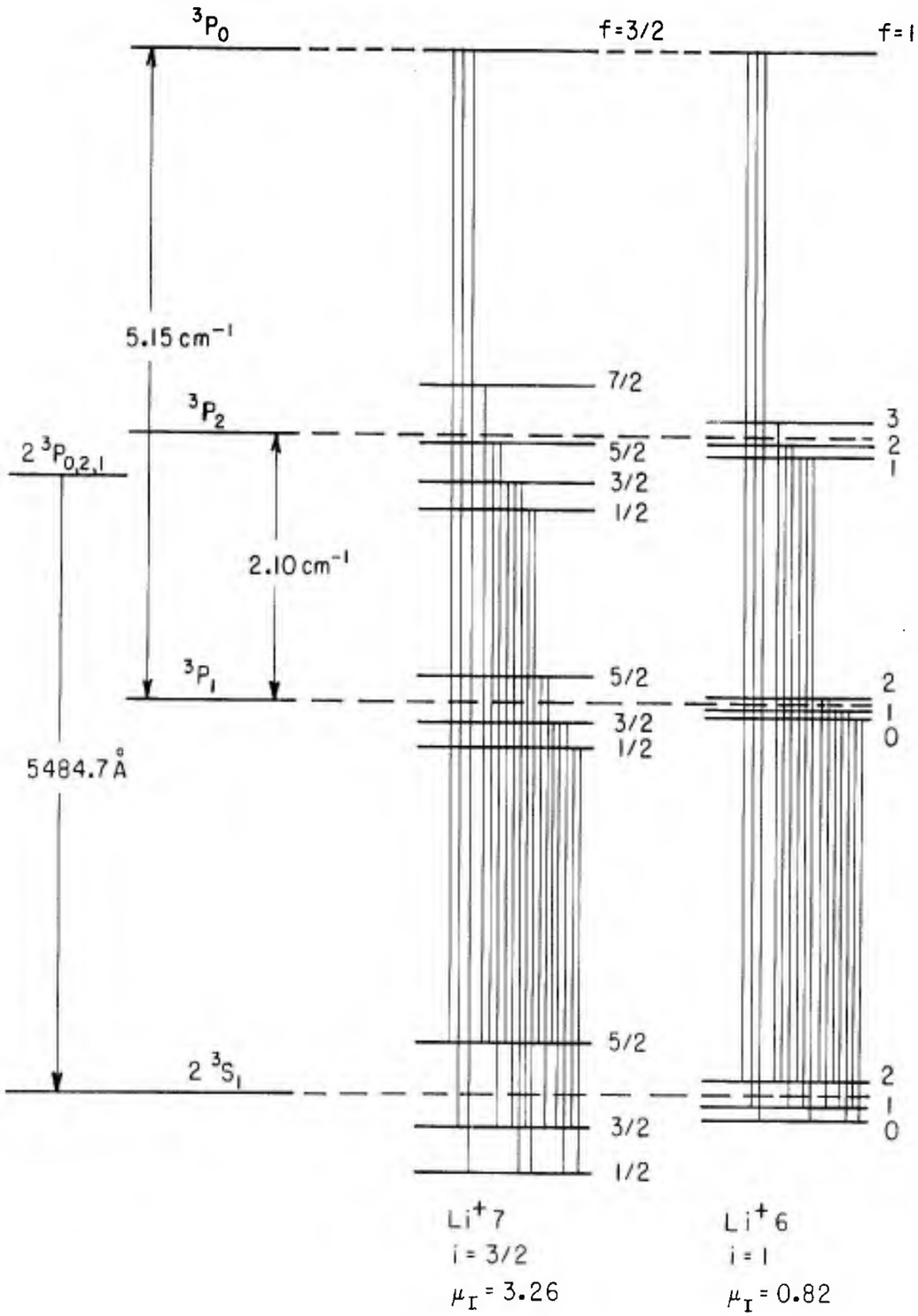



FIGURE 7. Fine and hyperfine structure of $Li^+$ ($2\,^3P_{0,2,1} \longrightarrow 2\,^3S_1$).

structure separation (which is proportional to $\alpha^2(Z-1)^3/n^3$)[2] is quite large compared to that of neutral helium (29.6 kMc/sec and 2.30 kMc/sec) and requires working in the higher microwave regions. However, a measurement to an accuracy of 10 Mc (a few times greater than the half-width of the transition line) would mean an improvement of 3 orders of magnitude over the optical values and it should be possible to go at least one order of magnitude better than this. The method proposed is that of electron bombardment ionization and polarization excitation developed by Lamb[3] in measuring the analogous structure of He.

In a one-electron process the Li atom would be simultaneously ionized and excited and the transition down to the $2\,^3S_1$ state would be observed. As Lamb has demonstrated[3], the polarization of the decay light is dependent on the direction of bombardment and on the relative populations of the sublevels. If microwave transitions are induced which change the relative populations of the levels, the light intensity along a given axis will vary (the total intensity remaining constant), and hence it will be possible to detect the transitions.

Calculations have begun on the ionization and excitation cross sections. Starting with a beam of neutral lithium atoms and with an electron current of a few hundred ma crossing the beam, we seek to determine the absolute population of the desired state and the transition probability between sublevels for practical microwave powers, with the aim of determining the order of magnitude of the effect we hope to observe. The excitation probability and decay light polarization are strongly peaked functions of the bombarding electron potential.

Two alternative means of producing a polarized 3P state are also being considered: (1) simple electron bombardment excitation of Li ions produced by the evaporation of β-eucryptite ($Li_2O \cdot Al_2O_3 \cdot 2SiO_3$) from a heated filament ($T > 1136\ ^\circ C$) is simpler than the two-electron process but has the disadvantage of low concentration of $Li^+$ (10 ma per $cm^2$ of coated filament surface at 1226 °C [4]); (2) optical excitation from the $2\,^3S_1$ state by polarized resonance radiation, following bombardment excitation ionization from the ground state. In this case detection would be more difficult due to the background of scattered radiation.

In a two-electron (helium type) system, the fine structure is due to spin-orbit coupling for each electron, and spin-other-orbit and spin-spin interactions between the two electrons. Bethe and Salpeter[2]

use the Pauli approximation to solve the Breit equation (the two-electron Dirac equation with the relativistic retarded interaction between electrons included) and find the perturbing terms in the Hamiltonian corresponding to these interactions to be

$$\text{(Spin-orbit)} \quad H_3 = \frac{\mu}{mc} \left\{ \left[ \bar{\varepsilon}_1 \times \bar{p}_1 + \frac{2e}{r_{12}^3} \bar{r}_{12} \times \bar{p}_2 \right] \cdot \bar{S}_1 + \left[ \bar{\varepsilon}_2 \times \bar{p}_2 + \frac{2e}{r_{12}^3} \bar{r}_{21} \times \bar{p}_1 \right] \cdot \bar{S}_2 \right\}$$

and $$\text{(spin-spin)} \quad H_5 = \frac{4\mu^2}{r_{12}^3} \left[ \bar{S}_1 \cdot \bar{S}_2 - \frac{S(\bar{S}_1 \cdot \bar{r}_{12})(\bar{S}_2 \cdot \bar{r}_{12})}{r_{12}^2} \right].$$

The fine structure levels for a $^3P$ state, referred to their center of gravity, are given by[3]:

$$E_0 = -2C + D,$$

$$E_1 = -C - 5D,$$

and

$$E_2 = C + D,$$

where C and D are the expectation values of $H_3$ and $H_5$ respectively. At present the electronic wavefunctions used in the calculation of C and D are very poor and so a precision measurement of the splitting would not shed any light on any higher order radiative corrections to the Hamiltonian.

Recently, Pekeris[5] has used variational methods with the aid of machine computation of determinants of orders up to 1078 to find wavefunctions for the calculation of the ground state energy of He to .001 $cm^{-1}$. Hence, fairly accurate wavefunctions for He-type atoms are obtainable. A comparison of precise experimental values for the $Li^+$ fine structure with theoretical values obtained with accurate wavefunctions will provide an estimate of the radiative and higher order corrections.

Program for the next interval: During the next quarter the calculation presently underway will be completed and preliminary design of the apparatus will be undertaken.

*This research was supported also by the Air Force Office of Scientific Research under Contract AF 49(638)-996.

1. H. Schüler, Z. Physik 42, 487 (1927); P. Güttinger and W. Pauli, Z. Physik 67, 743 (1931).

2. Bethe and Salpeter, Quantum Mechanics of One- and Two-Electron Atoms (Academic Press, New York, 1957).

3. Lamb, Phys. Rev. 105, 559 (1957).

4. Allison and Kanegai, Rev. Sci. Instr. 32, 1090 (1961).

5. Pekeris, Phys. Rev. 115, 1216 (1959).

## E. HYPERFINE STRUCTURE OF METASTABLE KRYPTON*

(L. Y. Chow Chiu, W. Faust, C. Summers)

The calculations to determine the nuclear moments of $Kr^{83}$ from the observed hyperfine splittings are still under way. The results of these calculations will be presented in a future report.

*This research was supported by the Air Force Office of Scientific Research under Contract AF 49(638)-557.

## F. THE METASTABLE LITHIUM ATOM*

(L. Y. Chow Chiu, R. Novick)

During our last attempt to search for metastable Li atoms, noise from stray ions and electrons developed when the electron bombarder was turned on. After the detector had been adequately shielded from the source, the noise decreased markedly.

During the past quarter we have searched for metastable Li atoms again without success. From the noise level of the detector, the beam intensity of metastable Li atoms (if present) at the detector must be smaller than a 4 cm galvanometer deflection ($10^6$ electrons/sec). The beam intensity of the ground state which was detected by an 0.001 in. hot tungsten wire was $1.5 \times 10^4$ cm galvanometer deflection. We have used the same tungsten wire (cold) with bias reversed to detect metastable atoms. In order to increase the sensitivity by a factor of 40 (due to solid angle increase, when the collimating slit is wide open) we

have also used the collector surface as a detector. However we did not detect metastable atoms in either case. The workability of the electron bombarder was checked by producing metastable Hg atoms[1] ( $^3D_3$ state, 9 ev above ground). The same oven and bombarder were used and the metastable Hg was detected by the same detector.

If we use Pietenpol's[2] lifetime of $^4P_{5/2}$ state of Li to calculate the decay factor, an upper limit on the cross section for producing metastable Li can be calculated as follows:

Oven temperature $T = 748\ ^{\circ}K$,

Most probable velocity in the beam $= a = 1.78 \times 10^5$ cm/sec,

Lifetime of the state(Pietenpol's value[2]) $\tau = 1.6 \times 10^{-5}$ sec,

Distance between source and detector $\ell = 15$ cm,

The decay factor $= e^{-t/\tau} = 1/190$.

If we assume the efficiency for detecting both the ground and metastable state to be 1, and if the collision quenching with other residue gas in the path can be neglected, the number of metastable atoms detected, $N_1$, can be expressed as:

$$N_1 = N\, e^{-t/\tau} \Delta\Omega \ ,$$

and

$$N = N_0\, J \sigma\, T \frac{1}{\Delta\Omega} \ ,$$

where $N$ is the number of metastable atoms leaving the source; $\Delta\Omega$ is the fraction of solid angle in which atoms can reach the detector after leaving the source; $N_0$ is the number of ground state atoms detected with the same fraction of solid angle $\Delta\Omega$, $N_0 = 1.5 \times 10^5 \times 40$ cm galvanometer deflection; $T$ is the time spent in the bombarder, $T = 6.1 \times 10^{-6}$ sec; $J$ is the bombarding electron current, $J = 10^{19}$ electrons/cm$^2$-sec; and $\sigma$ is the cross section for producing the metastable atoms. Since the metastable beam of Li detected corresponded to less than a 4 cm galvanometer deflection

$$N_1 = N_0\, J \sigma\, T\, e^{-t/\tau} < 4 \ ,$$

or

$$\sigma < 2 \times 10^{-17}\ \text{cm}^2.$$

Therefore the upper limit of the cross section for producing the metastable Li atom by electron bombardment is $2 \times 10^{-17}$ cm$^2$.

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*This work was supported by the Office of Naval Research under Contract Nonr-266(45).

I. W. Lichten, Phys. Rev. 109, 119 (1958).

2. Pietenpol, Phys. Rev. Letters 7, 64 (1961).

## II. PROPERTIES OF RADIOACTIVE ATOMS

### A. HYPERFINE STRUCTURE OF THE METASTABLE TRITIUM ATOM*
(J. Gruenebaum and P. Kusch)

The purpose of this series of experiments is to measure the hyperfine structure of the metastable hydrogen, deuterium and tritium atoms,[1] so that the ratios of these quantities with the corresponding previously measured values[2] for the ground states of these atoms can then be compared with their theoretically calculated values.[3] The hydrogen measurement has been completed[1] and we are currently working on deuterium.

During the past quarter we have made some modifications in the apparatus to improve its overall performance. The power supply for the exciter has been rebuilt - it is now regulated to provide a constant bombarding current so as to improve the stability of the beam.

Program for the next interval: We expect to make further measurements and theoretical calculations of the anomalous effects discussed in the last Quarterly Report.[4]

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*This work was supported by the Office of Naval Research under Contract Nonr- 266(45).

1. CRL Quarterly Report, Sept. 15, 1960, p. 26.

2. L. W. Anderson, F. M. Pipkin, and J. C. Baird, Jr., Phys. Rev. 120, 1279 (1960).

3. M. Sternheim, Ph.D. Thesis, Columbia University, 1961.

4. CRL Quarterly Report, Sept. 15, 1961, p. 30.

### B. HYPERFINE STRUCTURE OF $O^{15}$*
(H. Feldman)

This investigation has been delayed by the faulty operation of the Van de Graaff accelerator. The deuteron beam from the Van de Graaff accelerator is used to produce $O^{15}$ through the reaction $N^{14}(d,n)O^{15}$.

Program for the next interval: When the Van de Graaff is again operating satisfactorily, attempts will be made to observe the rf resonance corresponding to the transition between the $F = 3/2$, $m = 1/2$ and the $F = 1/2$, $m = -1/2$ levels in the $^3P_1$ state of $O^{15}$.

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*This research was supported by the Office of Naval Research under Contract Nonr-266(45).

## C. HYPERFINE STRUCTURE OF EXCITED STATES OF Na ISOTOPES* (R. J. Goshen)

The optical double resonance method has been used during the last quarter to observe the effect of coherence narrowing on the measurement of the radiative lifetime of the $3\ ^2P_{3/2}$ state of $Na^{23}$. Interference effects occur when several atoms are radiating and these result in an effective lifetime, T, where $T = \tau ( 1 - ax )^{-1}$ (1,2), and

$\tau$ = natural radiative lifetime,

$a = C ( F, J, I ) < 1$,

$$x = 1 - \exp \left[ - \frac{\pi^2}{2} \left( \frac{2F + 1}{2I + 1} \right) \frac{n L}{\tau k_o^3 V} \right],$$

where V = rms velocity and $L \approx (\text{volume})^{1/3}$.

The technique involves measuring the half-width of zero field, $\Delta F = 1$, rf hyperfine resonances over the temperature range 100 to 250 °C. We then have for the observed half-width

$$\Delta \nu_{1/2} = \frac{1}{\pi T} = \frac{1}{\pi \tau} ( 1 - ax ) + \text{Collision self-broadening term}.$$

The taking of data will be completed shortly and a plot of observed T vs number of atoms / cc will be given in the next quarterly report, together with a theoretical calculation based on the formulas given above. From these the natural radiative lifetime $\tau$ can be determined.

Serious difficulties have arisen in the preparation of a resonance cell for measurement of the hyperfine structure and nuclear

moments of radioactive $Na^{22}$ by the double resonance method. The $Na^{22}$ is produced by $Mg^{24}(d,\alpha)$ and the $Mg^{24}$ target is found to be contaminated by natural $Na^{23}$. In fact, the specific activity is such that the transition $\Delta\nu_{2-1}$ in $Na^{23}$ at 36 Mc will completely mask the transition $\Delta\nu_{9/2-7/2}$ at about 34 Mc in $Na^{22}$. In addition, natural Na contamination also exists in the glassware and other apparatus involved in producing the cell and is present in amounts comparable to the number of $Na^{22}$ atoms available. It is doubtful that any reasonable efforts toward further purification of the $Mg^{24}$ or cleansing of the distillation apparatus will raise the level of specific activity in a significant manner. Other production schemes involving $Ne^{21}$ and $F^{19}$ targets also appear to be unfeasible.

Under these circumstances our best hope seems to lie in improving the resolution of our spectrometer and it is to this end that our future effort will be directed. This aim is accomplished by equipping our apparatus to investigate the 5P third excited state rather than the 3P first excited state. From a calculation based on the oscillator strengths of the optical transitions[3] we see that

$$\tau_{3P} = 1.8 \times 10^{-8} \text{ sec},$$

$$\tau_{4P} = 1.12 \times 10^{-7} \text{ sec},$$

$$\tau_{5P} = 7.43 \times 10^{-7} \text{ sec}.$$

Thus the respective half-widths are

$$\delta_{1/2}(3P) = 18 \text{ Mc},$$

$$\delta_{1/2}(4P) = 2.84 \text{ Mc},$$

$$\delta_{1/2}(5P) = 429 \text{ Kc}.$$

On the other hand, we find that[3]

$Na^{22}$: $A_{3P} = 7.67$,

$A_{4P} = 2.21$,

$A_{5P} = 1.13$,

$Na^{23}$: $A_{3P} = 19.5$,

$A_{4P} = 5.61$,

$$A_{5P} = 2.87.$$

We see that the half-widths decrease more rapidly than the hyperfine structure separations and that transitions in the 5P state are completely resolved despite the presence of both isotopes. If sufficient signal-to-noise ratio can be obtained in this state then the difficulties previously mentioned can be overcome with rather reasonable precautions.

The optical transition from $5\ ^2P_{3/2} \longrightarrow 3\ ^2S_{1/2}$ is located at 2853 Å. Getting sufficient power into this pumping line is expected to present the major problem. A flow type lamp must be constructed because there is no alkali resistant glass available with a cutoff that far into the uv. The rf power required is only about 14 watts for saturation of the hfs transition, so that in this respect conditions are much better than in the 3P state. There will certainly be no problems with glow discharges. Polarizers, filters, etc. are all available for this wavelength as are high frequency power transistors for obtaining a sweep of the rf.

We have also set up a new apparatus to observe level crossings in the $4\ ^2P_{3/2}$ state of $Na^{23}$. The hyperfine levels involved are

$$(F, m_F) = (2,-2) \text{ and } (1,0)$$

$$(3,-2) \qquad (2,0)$$

$$(3,-3) \qquad (2,-1)$$

$$(3,-1) \qquad (2,1)\ .$$

We will make high precision measurements of the magnetic field for each crossing point and from these we can obtain a very accurate determination of $g_J$ for the $4\ ^2P_{3/2}$ state of Na together with precise values of the hyperfine intervals.

Program for the next interval: We will finish taking data on the coherence narrowing effect in the 3P state of $Na^{23}$. Then the optical and rf systems will be charged for the 5P state and we will attempt to detect the 5P hyperfine transitions for natural Na. At the same time we will try to observe level crossings in the 4P state.

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*This research was supported by the Office of Naval Research under Contract Nonr-266(45).

1. J. P. Barrat, J. phys. radium 20, 858 (1959).

2. F. Byron, CRL Quarterly Report, Sept. 15, 1961, p. 41.

3. R. Goshen, CRL Quarterly Report, Sept. 15, 1961, p. 35.

## D. HIGH-SENSITIVITY OPTICAL DOUBLE RESONANCE*
(R. Kohler)

The goal[1] of this work is the construction of a high sensitivity double resonance spectrometer for measuring spins and moments primarily of radioactive isotopes of Cd and of other alkali earths. The Cd sample is placed in a magnetic field which takes the $^3P_1$ state into the Paschen Back effect of the hyperfine structure to create basically three sets of sublevels, $M_J = 0, \pm 1$, each set separated from the others by intervals larger than the width of the $^3P_1$ resonance line of natural Cd. The center set, $M_J = 0$ coincides with the natural Cd resonance line. This coincidence permits use of the well established principle of detection of double resonance by frequency change.[2,3,4] Radiation from a natural Cd lamp selectively excites only the $M_J = 0$ sublevels of the $^3P_1$ state of the sample isotope. Radiation scattered from the sample is then viewed through interposed zero field natural Cd vapor, which selectively absorbs radiation from the $M_J = 0$ sublevels, but not from the $M_J = \pm 1$ sublevels. Transitions from the $M_J = 0$ sublevels to $M_J = \pm 1$ are induced by microwave fields. Light reradiated from $M_J = \pm 1$ gets through the Cd vapor, and the resulting increase in light permits detection of the microwave transition.

During the last quarter installation of a 12 inch Harvey-Wells magnet was completed. An 18 ft horizontal and 9 ft vertical bench was added to this. Most of the microwave components have now been gathered. Tests of the transmittance of a preliminary absorption cell have been carried out with a small monochrometer to reject most of the light not in the Cd resonance line. Transmittances of about $10^{-3}$ were observed. Transmittances of about $10^{-5}$ are expected, but these cannot be observed with the present monochrometer, which does not reject the unwanted light down to this order of magnitude. Currently a practical method for isolating the resonance line to the required degree is being sought and several techniques have been proposed.

Program for the next interval: It is expected that the spec-

trometer will be completed in the next quarter.

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*This research was also supported by the Air Force Office of Scientific Research under Contract AF-AFOSR-62-65.

1. CRL Quarterly Report, December 15, 1960, p. 29.

2. R. H. Kohler, Phys. Rev. 121, 1104 (1961).

3. C. V. Stager, Ph.D. Thesis, Department of Physics, M.I.T., 1960.

4. C. Brot, J. phys. radium 22, 412 (1961).

## E. OPTICAL DOUBLE RESONANCE STUDIES OF RADIOACTIVE ATOMS*

(F. Byron, M. McDermott, R. Novick, B. Perry)

During the last quarter experiments using the optical double resonance technique on radioactive $Cd^{107}$ have been continued and new data concerning the nuclear moments have been obtained.

An improvement in the preparation of resonance cells used in the studies on $Cd^{107}$ has resulted in an increase in the signal over that observed in earlier runs by a factor estimated to be approximately 100. An improvement of this magnitude was not expected and until further runs are made it is not possible to state the cause for the increase with certaintly. It is apparent, however, that the improvement is associated with careful attempts to minimize the contamination of the cell from foreign gases. Virtually no broadening of the resonance due to the presence of foreign gas was observed whereas in earlier attempts the resonances were at least a factor of two broader than resonances observed in stable cadmium cells under similar conditions.

With the increased signal it was possible to observe resonances between individual Zeeman levels at magnetic fields where the resonances were well separated. Since an approximately equal quantity of $Cd^{109}$, also of spin 5/2, was produced in the natural silver target, the resonances due to this isotope were observed simultaneously. In most cases these were resolved from the $Cd^{107}$ resonances since the magnetic moments of the two isotopes proved to differ by nearly 25 %. The upper trace in

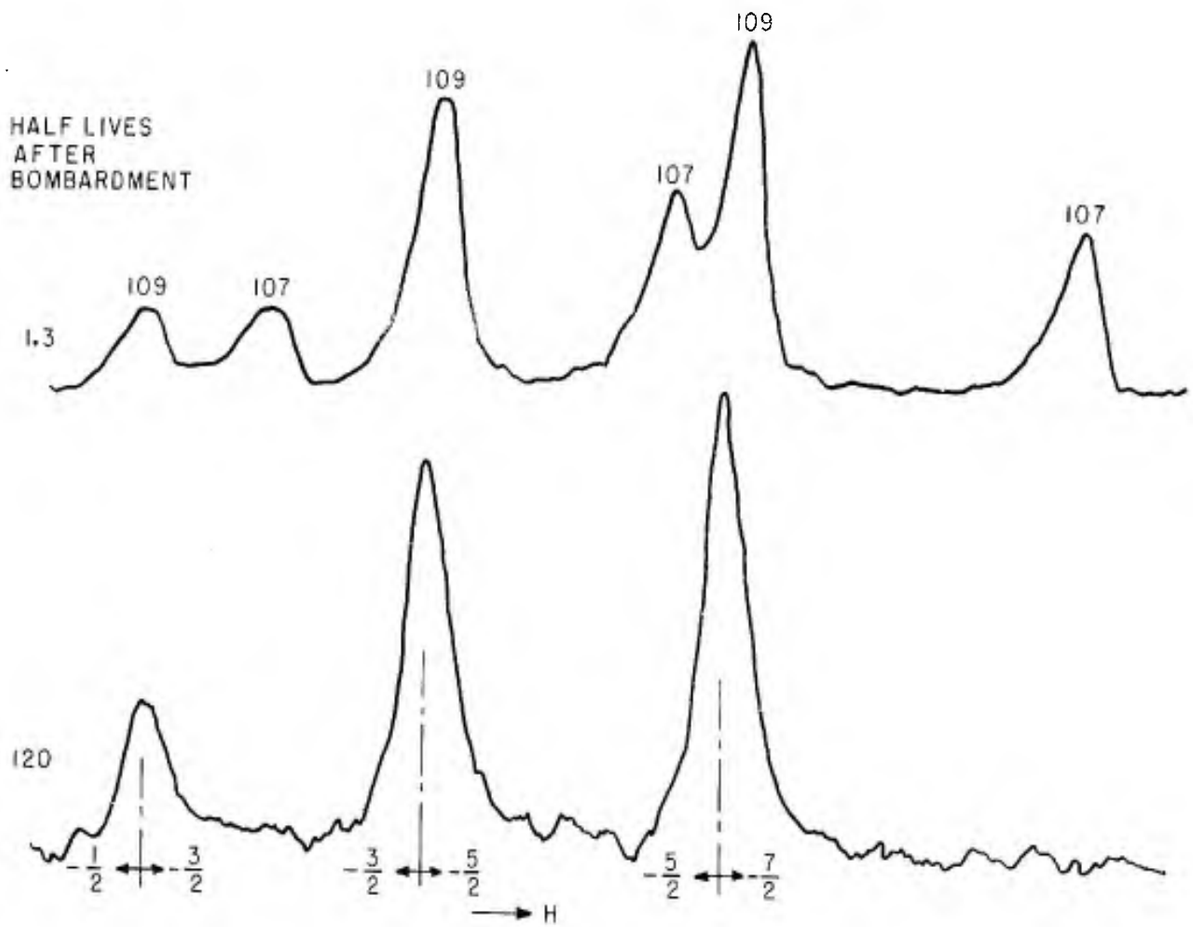


FIGURE 8. Zeeman resonances in the F = 7/2 state of $Cd^{107}$ and $Cd^{109}$, $\nu$ = 120 Mc/sec.

Fig. 8 shows one-half of the observed resonances in the F = 7/2 states of $Cd^{107}$ and $Cd^{109}$, shortly after production in the cyclotron. The lower trace was taken much later at a time when only the $Cd^{109}$ activity would be expected to remain.

The decay of the amplitude of a single resonance with time was observed for the purpose of positively identifying the isotopes involved. Variations in the resonance amplitude due to lamp output or temperature fluctuations were corrected for by normalization against the amplitude of a resonance in $Cd^{109}$. The latter isotope has a 470 day half-life and should not decay noticeably during a run. The results are plotted in Fig. 9 . The decay is best fit assuming a half-life of 427 minutes, which agrees within the experimental uncertainties with the value of 404 minutes, measured[1] from the nuclear decay.

The hyperfine interaction constants were obtained by fitting resonances observed at 90 and 120 Mc/sec. Since the location of the resonances was not known in advance, it was not possible to use the most favorable sweep rates. As a result, corrections to the resonance positions due to the effect described in a preceding article[2] were not negligible. When the correction $\omega_o' = \omega_o \pm \Delta_{1/2}\beta$ was applied a substantial improvement in the internal consistency of the data was obtained. This can be regarded as a partial verification of these corrections.

The interaction constants obtained are A = - 854.7(10) Mc/sec and B = - 164(3) Mc/sec. From these we can obtain a nuclear magnetic moment $\mu_{107} = -0.6166\ (7)\ \mu_N$ and a quadrupole moment, Q = + 0.78 barns.

Production methods for $Cd^{113m}$, $Zn^{63}$ and $Zn^{65}$ have been investigated. Their half-lives are, respectively, 15 yr, 38 min and 250 days. Study of the short-lived zinc isotope will be made more difficult because of its 73% $\beta^+$ (2.3 Mev) decay mode. For the other two isotopes, the reactions decided on are $Pd^{110}(\alpha,n)Cd^{113m}$ and $Cu^{65}(p,n)Zn^{65}$. Estimated cross sections are 100 mb at 20 Mev and 140 mb at 4.7 Mev, respectively. 99.999+ % pure copper and 99.99+ % pure palladium foil with naturally occuring isotopic abundances will be used for production.

Program for the next interval: Another run on $Cd^{107}$ will be made and work on the feasibility of studying the new isotopes mentioned will continue.

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*This work was also supported by the Air Force Office of Scientific Research under Contract AF 49(638)-996.

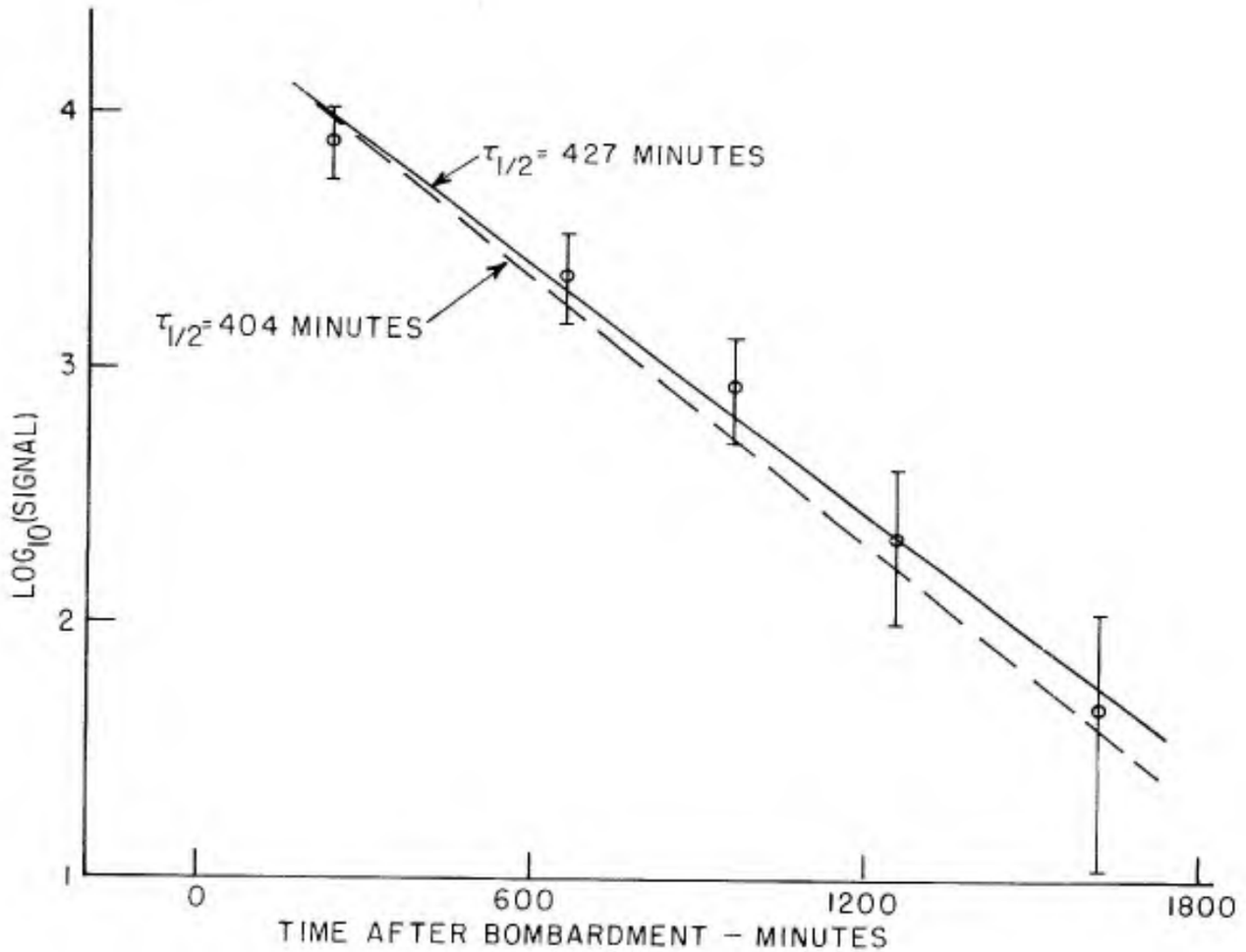


FIGURE 9. Decay of (7/2,7/2) ⟷ (7/2,5/2) resonance in $Cd^{107}$, $\nu$ = 60 Mc/sec.

1. L. A. Delasso, L. N. Ridenaur, R. Sherr and M. G. White, Phys. Rev. 55, 113 (1939).

2. See p. 7 of this report.

### F. MOLECULAR BEAM VELOCITY SELECTOR*
(M. Hessel, P. Kusch)

A new program for the study of the interaction potential of molecules through measurements of their collision cross section has been started.

Minor modification of the existing velocity selector equipment is under way.

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*This research was supported also by the Air Force Office of Scientific Research under Contract AF 49(638)-557.

## III. PHYSICS OF MOLECULES

### A. MASER BEAM SPECTROSCOPY*
(L. Krisher, H. Lecar)

The low frequency square wave generator described in the last Quarterly Report has been constructed and tested. This equipment allows the focusser electrode to be modulated by a 130 cps square wave, which will be followed by a phase sensitive detector at this frequency.

Parallel "T" networks have been constructed at 130 cps and the operation of the modified spectrometer awaits the completion of the phase detector. Work on the new beam maser has been postponed because of the work on the maser paramagnetic resonance spectrometer described in section V-B.

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*This work was also supported in part by the National Science Foundation under NSF - G 18811.

## B. MICROWAVE ABSORPTION SPECTROSCOPY*
(L. Krisher)

A new experimental program has been started for the purpose of studying the rotational spectra of various organic and inorganic molecules. The laboratory apparatus consists of a conventional Stark-modulated microwave spectrometer,[1] with phase-sensitive detection at the modulation frequency of 100 kc/sec.

Three absorption cells have been constructed, of length 6 ft, 12 ft and 15 ft. These cells consist of lengths of copper waveguide with an internal "septum", i.e. a copper plate parallel to the large cross sectional dimension, insulated by a pair of teflon strips. A gas handling system has also been constructed. A 100 kc square wave generator, variable to 2000 volts, has been built and tested. The operation of the final apparatus requires the completion of a 100 kc receiver and phase sensitive detector.

This apparatus will be used to study a variety of problems. The analysis of a microwave spectrum affords very precise data with regard to the structure of molecules, (i.e. internuclear distances and bond angles), dipole moments, and the heights of potential barriers which hinder various internal motions. A large number of these internal barriers have been measured in a number of laboratories for three-fold symmetric groups such as the methyl or silyl compounds, $CH_3$- or $SiH_3$-. It is also possible to study such hyperfine interactions as quadrupole coupling constants in molecules, which afford a measure of the electronic distribution in the molecular bonds.

Initially, an effort will be made to measure the internal barrier of acetyl iodide, $CH_3COI$, which is one of a series of molecules of the type $CH_3COZ$. Several members of this series have been extensively studied.[2,3]

It should be noted that this spectrometer is a rather general instrument consisting of a microwave source, cell, and microwave detector. Several types of cells can be substituted to obtain various types of information, e.g. a conventional Stark cell, a Zeeman cell, or a quartz cell for reactive molecules.

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*This research was also supported by the National Science Foundation under NSF - G 18811.

1. McAfee, Hughes, and Wilson, Rev. Sci. Instr. 20, 821 (1949).

2. L. C. Krisher and E. B. Wilson, J. Chem. Phys. 31, 882 (1959).

3. L. C. Krisher, J. Chem. Phys. 33, 1237 (1960).

## C. MICROWAVE SPECTROSCOPY OF RADICALS
(G. Ehrenstein)

Experimental work on the $J = 7/2$ level of $O^{17}H$ has been completed. Of the 42 allowed transitions, 4 main lines and one satellite line have been observed. The frequencies of these lines are in agreement with a relatively simple model for the OH radical. Additional lines were not observed because of intensity limitations.

The effect of hyperfine interactions is illustrated in Fig. II, which is not to scale. In the absence of hyperfine structure, the $J = 7/2$ level would be split into two levels only, due to interaction between the molecular rotation and the electronic motion. However, each $\lambda$-doubling level is split into 6 $F_1$ levels due to the $O^{17}$ nuclear spin of 5/2 (hereafter referred to as $I_1$). The splittings for the upper and lower levels are different because the interaction energy for the upper $\lambda$-doubling level is of the form $(X + Y)\, I_1 \cdot J$, whereas the interaction energy of the lower $\lambda$-doubling level is of the form $(X - Y)\, I_1 \cdot J$. X and Y will be examined further in connection with the numerical results. Due to the H nuclear spin of 1/2, each $F_1$ level is split further into two F levels. The upper and lower $\lambda$-doubling levels for a given $F_1$ are split by different amounts.

The level structure gives rise to 42 allowed transitions. In general, the strongest lines correspond to transitions with $\Delta F = 0$, $\Delta F_1 = 0$. These are called main lines, and all other transitions are called satellites.

Four main lines (two doublets) have been observed. These are summarized in Table I, and are indicated by solid arrows in Fig. II. Identification was made by considering doublet splittings and resultant values of $\nu_0$, the $\lambda$-doubling frequency separation. The doublet splittings depend upon the hyperfine constants about the hydrogen atom, and not upon the hyperfine constants about $O^{17}$. Hence their value can be obtained from previous work on $O^{16}H$ hyperfine constants.[1] The value of $\nu_0$ for $O^{17}H$ can be approximately determined from the values of $\nu_0$ for $O^{16}H$ and for $O^{18}H$. These are easier to obtain than

TABLE I

Experimentally Measured Main Lines in $O^{17}H$ Hyperfine Structure

| Doublet | $F_1 = 5 \leftarrow F_1 = 5$ | $F_1 = 4 \leftarrow F_1 = 4$ |
|---|---|---|
| Lower Frequency (Mc) | 13,298.12 ±0.2 | 13,357.91 ±0.3 |
| Higher Frequency (Mc) | 13,304.00 ±0.3 | 13,362.91 ±0.3 |
| Experimental Doublet Separation (Mc) | 5.88 ±0.4 | 5.00 ±0.4 |
| Doublet Separation Determined from $O^{16}H$ Data (Mc) | 5.52 ±0.15 | 4.97 ±0.13 |
| Center of Doublet (Mc) | 13,301.34 ±0.2 | 13,360.69 ±0.2 |

those of $O^{17}H$ because of the simple hyperfine structure present. Accordingly, $\nu_0$ for $O^{18}H$ was determined experimentally. $\nu_0$ for $O^{16}H$ has been measured previously[1].

The results for $\nu_0$ are as follows:

| Isotopic Species | Experimental $\nu_0$ (Mc) |
|---|---|
| $O^{16}H$ | 13,438.41 ±0.05 |
| $O^{18}H$ | 13,234.16 ±0.1 |
| $O^{17}H$ | 13,333.98 ±0.3 |

The separations between centers of the two doublets of $O^{17}H$ determined the constant Y, which depends upon accurately-known molecular properties and on the hyperfine coupling constant "d". Thus, the experimental results determine d.

According to theory,

$$d = 3\ \mu_0\ \frac{\mu_{I_1}}{I_1}\left[\frac{\sin^2 \chi}{r^3}\right]_{av},$$

where $\chi$ is the angle at the $O^{17}$ nucleus between unpaired electron and internuclear axis and r the distance from electron to $O^{17}$ nucleus. Since $\mu_0$, $\mu_{I_1}$, and $I_1$ are known, d can be determined theoretically from the values of $(\sin^2 \chi)_{av}$ and $(1/r^3)_{av}$ for the unpaired electron in OH.

A simple model of the OH radical gives an electronic structure[2]: $1s^2\ 2s^2\ 2p^5$, with one unpaired $p_\pi$ electron about the $O^{17}$ nucleus. If this model is correct, $(\sin^2 \chi)_{av} = 0.8$. To determine $(1/r^3)_{av}$ for OH, one must correct the value determined from the fine structure of the ground state of the oxygen atom[3] to allow for the partial ionic character of OH. For the negatively ionized oxygen atom, the electrons will be more loosely bound than for the neutral atom; r will increase and $(1/r^3)$ will decrease. The ionic correction was computed, using empirical approximations of Dailey and Townes[4]. It was found that the ionic character decreases $(1/r^3)_{av}$ by about 11 - 15 %. The best resultant calculated value of d is

$$d = -384 \text{ Mc}.$$

Experimentally, $d = -414$ Mc.

The difference, 7.2%, is not large by the standards of molecular calculations. Furthermore, part of this difference may be due to the approximate nature of the ionic correction.

In addition to the 4 main lines, one satellite line was observed at 13,306.1 ±0.5 Mc. This line depends upon both X and Y. X is a linear combination of hyperfine coupling constants a, b and c, where

$$a = 2\ \frac{\mu_0\ \mu_{I_1}}{I_1}\ (1/r^3)_{av},$$

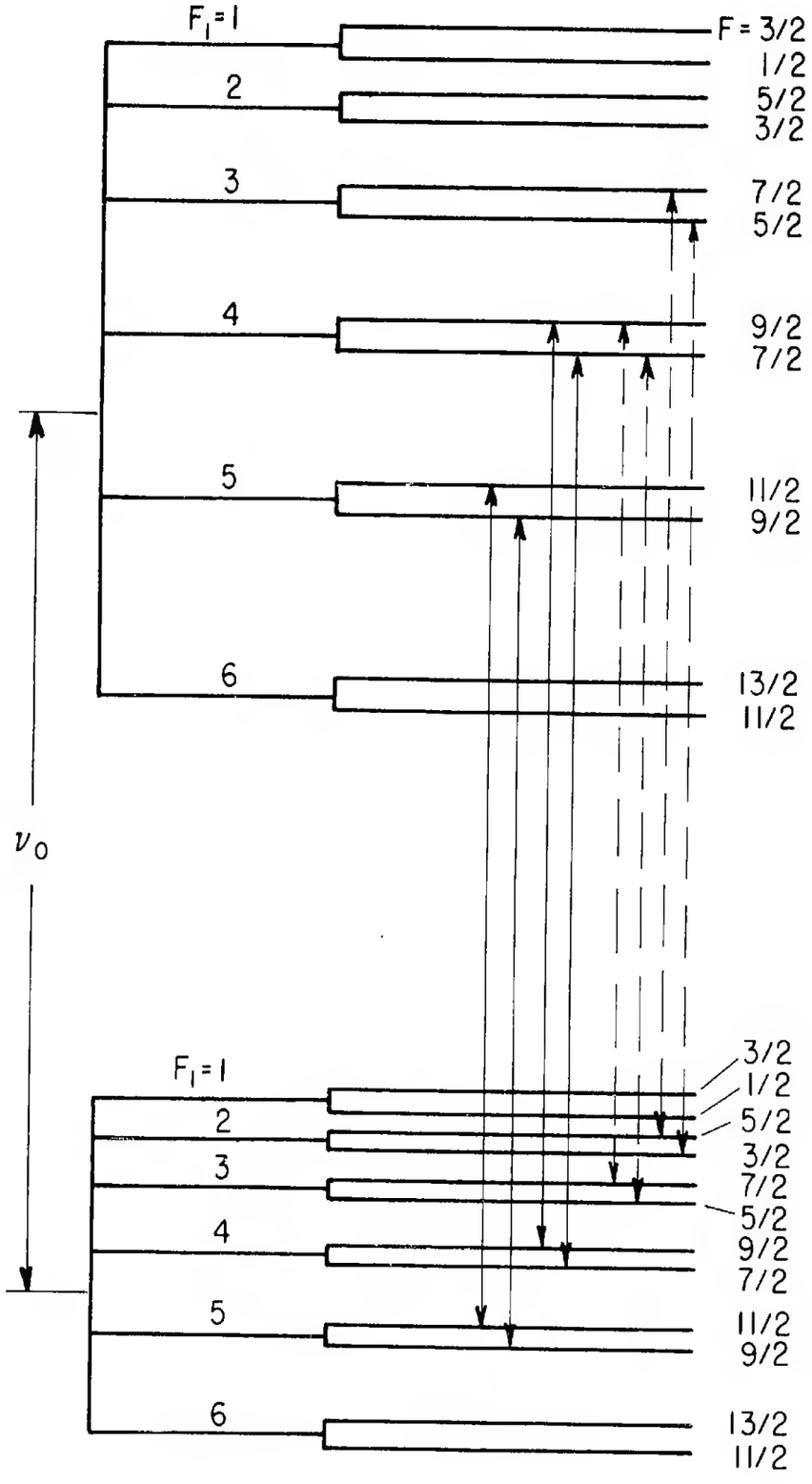


FIGURE 10. Energy level diagram for J = 7/2 level of $O^{17}H$.

$$b = -\frac{\mu_0 \quad \mu_{I_1}}{I_1} \left[ \frac{3\cos^2 X \quad - 1}{r^3} \right]_{av}$$

$$+ \frac{16}{3}\pi \frac{\mu_0 \quad \mu_{I_1}}{I_1} \psi^2(0),$$

$$c = 3\frac{\mu_0 \quad \mu_{I_1}}{I_1} \left[ \frac{3\cos^2 X \quad - 1}{r^3} \right]_{av}.$$

$\psi^2(0)$ is the probability density of electron spin at the $O^{17}$ nucleus.

If one computes a, b and c using the same model of OH and the same numerical values for the parameters as were used to compute d, and also assumes that $\psi^2(0) = 0$, then $X = -27.9$ Mc. If $\psi^2(0) \neq 0$, then the magnitude of X is somewhat increased.

The value of X can be determined experimentally from the position of the satellite line and the knowledge of which transition it is. Four reasonable possibilities are indicated by dashed arrows in Fig. 10. If the satellite transition is $F_1 = 4 \longleftarrow F_1 = 3$, then $X = -18.2$ mc. If the satellite transition is $F_1 = 3 \longleftarrow F_1 = 2$, then $X = -36.9$ Mc. The latter case seems more probable, since good agreement with theory can be obtained with a not unreasonable value of $\psi^2(0)$.

Summary: Four main lines (two doublets) of the $O^{17}H$ hyperfine structure have been observed. The doublet separations are in agreement with results of $O^{16}H$ hyperfine structure. The separation between centers of the doublets gives a value of $d = -414$ Mc, in good agreement with a simple model.

Program for the next interval: Work will begin on preparation of a paper for publication giving a complete description of the experiments on $O^{17}H$ hyperfine structure and on the OH dipole moment.

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1. G. C. Dousmanis, J. M. Sanders, Jr., and C. H. Townes, Phys. Rev. 100, 1735 (1955).

2. R. S. Mulliken and A. Christy, Phys. Rev. 38, 87 (1931).

3. T. Yamanouchi and H. Horie, J. Phys. Soc. Japan I, 52 (1952).

4. B. P. Dailey and C. H. Townes, J. Chem. Phys. 23, 118 (1955).

## IV. SOLID STATE PHYSICS

### A. COLOR CENTERS IN $TiO_2$ (RUTILE)

(R. Gazzinelli, R. Novick, Y. Yeh)

A new study has been started on color centers in rutile.

Today a large part of the total research effort in solid state physics is devoted to the problems of imperfections in crystals. Many important properties of solids are controlled by the nature of the imperfections rather than by the nature of the crystal lattice. An important type of lattice defect is the color center, which is an imperfection that absorbs light and may be responsible for the color of many crystals. Since the atomic structure of color centers is often paramagnetic, electron spin resonance techniques may be used to identify these centers, to determine their symmetry structure with respect to the lattice, and to obtain information on their interactions with the surroundings.

Okaya[1] reported that many strong and weak lines unrelated to the known $Fe^{+3}$, $Ge^{+3}$ and $Ti^{+3}$ lines were observed in rutile with a paramagnetic spectrometer with a sensitivity capable of detection $10^9$ spins/$cm^3$. Several of these strong and isotropic lines had g-values near 2.

Optical and infrared spectra of synthetic pure rutile, as well as $H_2$-reduced and $D_2$-reduced samples, revealed the existence of color centers. It has been proposed that interstitial hydrogen atoms may be responsible for these centers.[2,3]

A preliminary reflection type video spectrometer has been set up with the rutile crystal mounted at the end of a shorted waveguide inside a liquid helium cryostat. The crystal body resonance is used instead of the usual cavity resonance since greater sensitivity can be obtained from it due to higher Q-values and 100% filling factor. With this

simple system, paramagnetic impurity lines have been observed($Q \approx 15{,}000$).

A paramagnetic spectrometer with superheterodyne detection is being constructed(Fig. 11). In this system one stable microwave oscillator is used. The power is divided and one part goes directly to the mixer. The other part is modulated at 30 Mc/sec and fed to the sample which is used as a resonating structure. The reflected power from the sample is fed into the mixer and the power in the sidebands of the modulated input acts as the local oscillator frequency. The signal is detected, amplified and recorded.

It is hoped that with the increased sensitivity of the superheterodyne system a systematic study of the details of the lines observed can be made. Simultaneously a special cell has been constructed to study the infrared spectra of rutile at low temperatures. Measurements are in progress. An attempt will also be made to correlate the optical and paramagnetic spectra.

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1. A. Okaya, "Paramagnetic Resonance in Reduced Rutile," CRL Quarterly Report, March 15, 1960.

2. B. H. Soffer, "Studies of the Optical Absorption Spectra of Rutile Single Crystals," Technical Report 140, Laboratory for Insulation Research, M.I.T.

3. A. Okaya, "Paramagnetic Resonance in Reduced Rutile," CRL Quarterly Report, June 15, 1960.


## B. PARAMAGNETIC RELAXATION AT LOW TEMPERATURES
(F. Nash)

Analysis of the data presented in the last quarterly report is in progress. It is hoped that the chemical analyses (test for foreign paramagnetic impurities)and the theoretical calculations will be presented in the next report.

## C. THE INTERACTION BETWEEN A NEUTRAL MOLECULE AND A CONDUCTING SURFACE*
(F. Cook)

Work during the current period has consisted of implementing

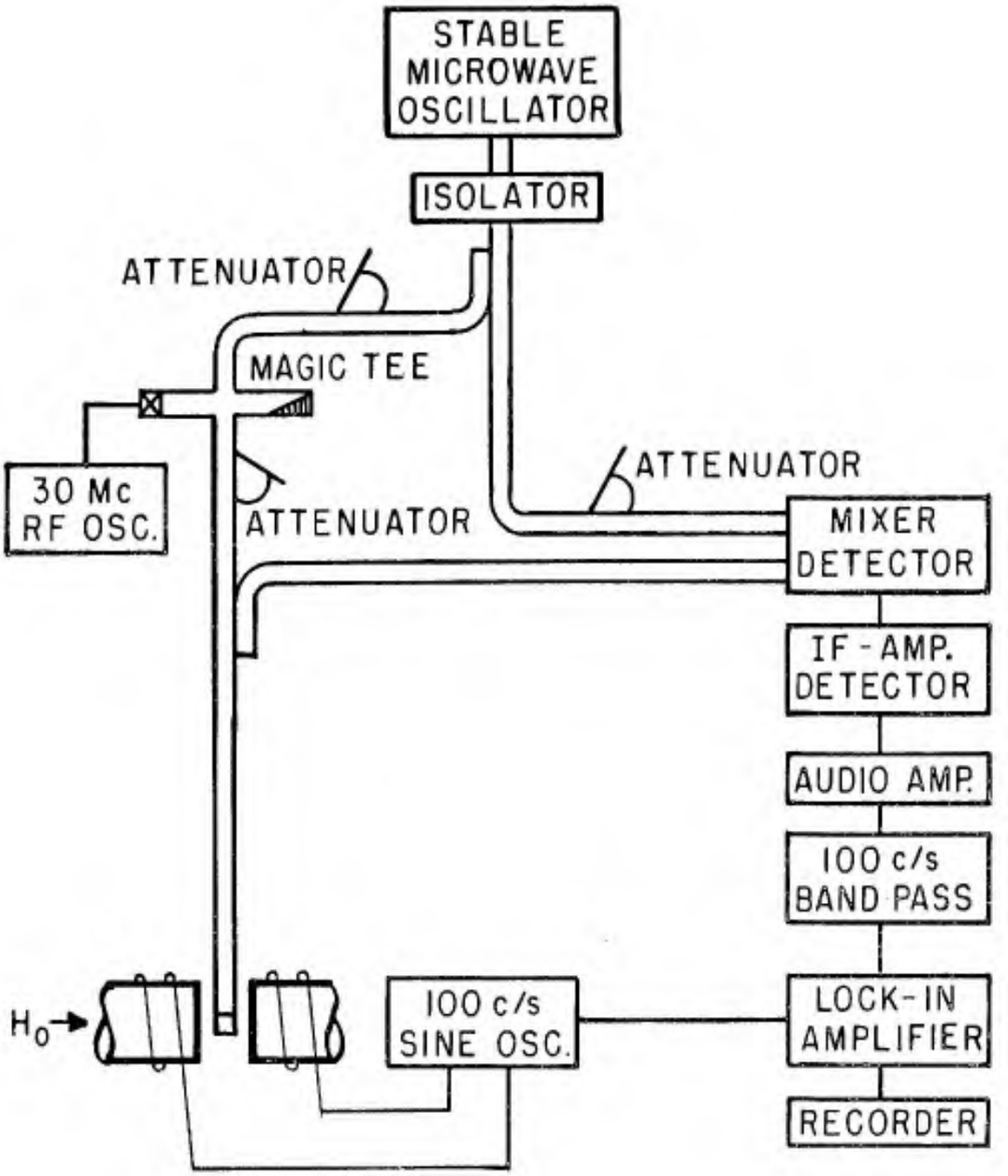


FIGURE II. Block diagram of superheterodyne detection system.

the modifications to the apparatus discussed in the preceding report. These changes involve incorporating the deflecting surface and collimating slit as parts of interferometers in order to provide an exact method of rendering the deflecting surface parallel to the beam. This work is nearly complete.

During the coming quarter the interferometric alignment method will be tested and subsequent runs with the apparatus attempted.

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*This research was also supported by the Army Research Office(Durham) under Grant DA-ARO(D)-31-124-G170.

## V. OPTICAL AND MICROWAVE MASERS

### A. INFRARED AND OPTICAL MASERS*
(I. Abella, H. Cummins, N. Knable)

#### 1. Ruby Maser

The pulsed ruby maser has been modified with the aim of increasing the power output for use in non-linear effect experiments. This was successfully accomplished, in large part due to increased efficiency of the new flashtube reflector and ruby cooling arrangements.

Second harmonic light[1] was obtained using KDP crystals, (class $\bar{4}2m$) which were cut so that red light was incident in the x-y plane 45 degrees to each axis[2].

The study of this light at high resolution is in progress. Preliminary results have been obtained using the 3.4 m Jarrell-Ash Spectrograph and 103-0 spectrographic plates. It has been noted that under conditions of maser operation producing maximum red light output the second harmonic is spread over an essentially continuous region about 3/4 $cm^{-1}$ wide, with most of the intensity distributed at the short wavelength end in a region 0.2 $cm^{-1}$ wide. Infrequently, for less than maximum maser output, some line structure has been observed.

These data are in qualitative agreement with the known properties of pulsed ruby systems. It is known, for example, that temperature variation within a high energy pulse could produce appreciable broad-

ening (toward longer wavelength) which would be observed to some degree in the second harmonic as well. In addition, mode structure[3] known to be present near threshold and to a certain extent even at higher excitation levels could produce the structure seen in the second harmonic.

These studies are to be continued using the spectrograph and the Fabry-Perot interferometer. The pumping lamp used at present may be a source of broadening. The lamp requires a series choke to prevent damage which limits the rate of discharge. New lamps will be tried to reduce this problem, and to obtain larger peak powers.

2. Cesium Maser

We have discussed at length the cesium vapor system in previous progress reports. During this period, final experiments were performed with the 4 inch system, but no oscillations were detected. Short (4 inch) systems have been extensively tested in this laboratory because the alignment of the mirrors can be carefully controlled by continuously observing the optical interference patterns. Inability to control alignment so precisely in existing maser systems has effectively blocked efforts to study dependence of the oscillation patterns on mirror alignment.

Failure to detect oscillations in the latest experiments(in which alignment was constantly controlled and all experimental conditions satisfactory) have led us to abandon the short system. Construction of a twenty inch system is therefore being completed. This system is similar to the shorter one in basic design. Although the ability to control the alignment interferometrically will be sacrificed, the five-fold increase in length (and gain) will considerably enhance the possibility of oscillation. Alignment of the new system will be controlled by autocollimation.

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*This research is also supported by the Air Force Office of Scientific Research under Contract AF-AFOSR-62-49.

1. Franken et al, Phys. Rev. Letters 7, 118 (1961).

2. Nye, Physical Properties of Crystals (Oxford University Press, London, 1957), Chap. VII.

3. I. D. Abella and C. H. Townes, Nature 192, 957 (1961).

## B. SENSITIVITY OF MICROWAVE SPECTROMETERS USING MASER TECHNIQUES*

(H. Lecar)

A paramagnetic resonance spectrometer employing maser techniques to obtain increased sensitivity has been described in previous reports. Experiments are in progress to test the sensitivity of this spectrometer.

In these experiments, a known amount of a paramagnetic sample is placed in the maser cavity and an absorption signal is observed with a measured monitoring power. The pump klystron is then turned on and the signal is observed as a decrease in the maser power output. Small changes in the orientation of the ruby crystal are used to vary the maser gain. The signal-to-noise ratio of the absorption signal is measured as a function of the maser gain. The increase in signal-to-noise ratio with increased gain can then be compared with the calculated value when the maser is used merely as a low-noise preamplifier. A microwave bridge is used to vary the power incident on the detector so that the conversion loss and noise figure of the detector are identical for differing amounts of power emerging from the maser cavity. The microwave circuit is shown in Fig. 12.

Further improvements in the sensitivity of this system can be obtained with the use of a circulator and input attenuator held at liquid helium temperature. These will prevent the amplification by the maser of the thermal noise emanating from the room-temperature waveguides.

Program for the next interval: During the next quarter the calibration of the spectrometer will be completed and a program of high-sensitivity paramagnetic resonance experiments will commence.

*This research was supported also by the National Science Foundation under Grant No. NSF-GI8811.

## C. RUBIDIUM ATOMIC CLOCK

(P. Davidovits, N. Knable)

The hyperfine structure of rubidium was first examined in an optically pumped cell by Alley, Dicke and Carver[1]. Although they had measured the resonance by direct detection of microwave absorption rather

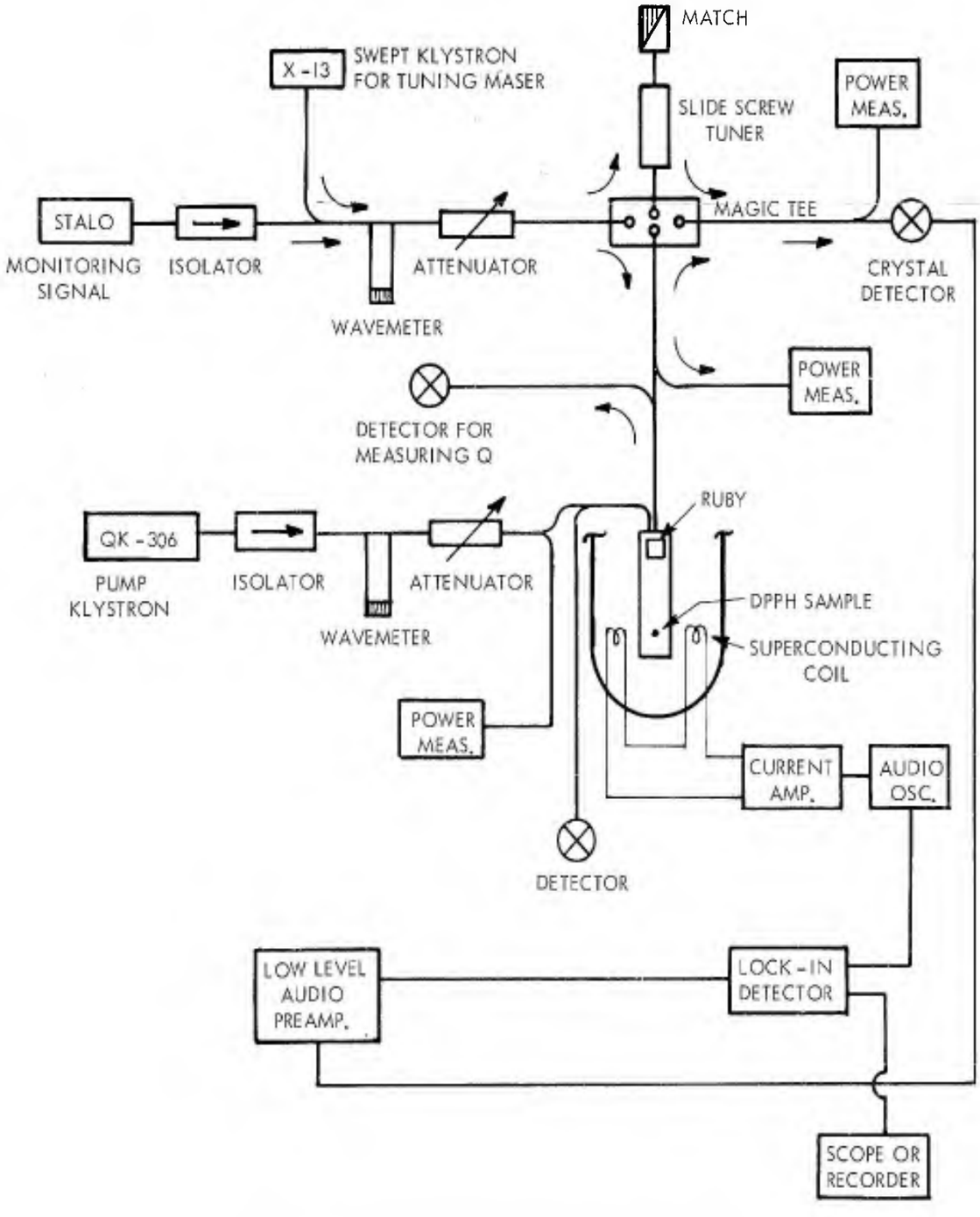


FIGURE 12. Microwave circuit of the maser paramagnetic resonance spectrometer.

than the absorption of the pumping light, their use of circularly polarized light in the pumping scheme was inefficient and powers less than $10^{-16}$ watts were measured as being derived from stimulated emission.

Work was started by P. Bender and N. Knable at the National Bureau of Standards in 1960 to make a self consistent oscillator by increasing the Q of a microwave cavity with the introduction of an optically pumped $Rb^{87}$ vapor. Earlier, Bender and Beaty[2] had constructed a clock using the optically pumped $Rb^{87}$ as a passive frequency standard and referring a harmonic of a crystal-controlled oscillator to the rubidium absorption line. They had measured line widths of the order of 10 cps at 6835 Mc with 50 db signal-to-noise ratios.

Although microwave gas masers have been constructed with other materials and methods of state separation, they have employed electric dipole transitions whereas the $Rb^{87}$ transition is magnetic dipole and has smaller transition probabilities by a factor of 1/137.

The goal of the work at N.B.S. was to determine whether or not a maser could be made. This involved determination of the life-time of $Rb^{87}$ in high concentration. It also involved the investigation of how high the Q of the cavity could be made when a suitable cell of adequate strength to hold the corrosive rubidium and withstand vacuum pressure was inserted. It was established experimentally that a maser could be made if the gain of the system used at N.B.S. could be increased by a factor of two. We hope to obtain this improvement by better pumping techniques and cavities of higher Q.

In April some of the N.B.S. equipment was brought to Columbia. It has recently been set up and resonances are now being observed. Work is being carried out by Mr. P. Davidovits and Dr. N. Knable at the Radiation Laboratory to make a self-consistent oscillator with the $Rb^{87}$ hfs ground state $m_F = 0 \longrightarrow m_F = 0$ transition and collaterally to investigate the nature of the pumping process, sources of relaxation of the oriented rubidium atoms, an accurate measurement of the Rb-Rb spin exchange cross section and the details of frequency shifts of the resonance line produced by pumping light intensity and spectral distribution, buffer gases and wall collisions, etc.

A brief description of the maser may be in order. Referring to Fig. 13 and Fig. 14 we see that a Rb discharge lamp produces photons emanating from the 5P levels to the two ground state levels $F = 2$ and $F = 1$. A cell containing $Rb^{85}$ in a buffer gas at suitable pressure

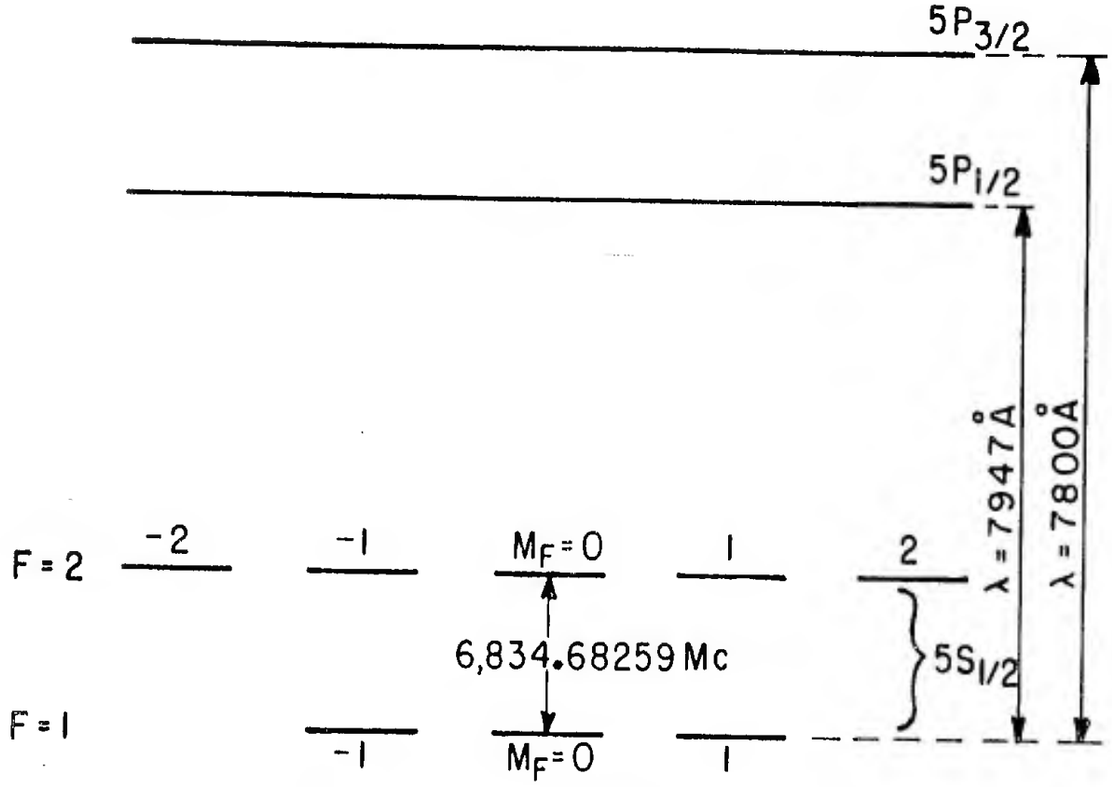


FIGURE 13. Simplified energy level diagram for $Rb^{87}$.

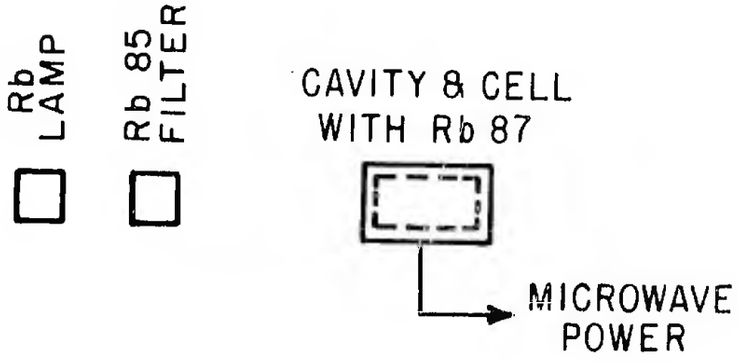


FIGURE 14. Simplified block diagram for the optical pumping.

possesses an absorption line in its hfs which absorbs photons of the $Rb^{87}$ emission spectrum corresponding to transitions to the F = 2 ground state levels. The light reaching the $Rb^{87}$ cell in the cavity thus has components which cause emission from the F = 1 ground state levels and after the short life of the 5P states we are left with a group state population having an excess of F=2 over F=1. The magnetic substates are separated by a weak guiding field. A cavity of high Q surrounds the cell which has a mode in which the rf fields are in the direction of the guiding field. Thus for a high enough Q, $Rb^{87}$ vapor pressure, light intensity and relaxation time, a photon from a spontaneous transition $m_F = 0$ to $m_F = 0$ in the ground state is preserved long enough to stimulate another transition and a resultant coherent cascade of photons ensues.

The power expected from the maser will be about $10^{-10}$ watts with a phase stability of 90 db and long-time frequency stability greater than 1 part in $10^{11}$.

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1. R. Dicke, T. Carver, and C. Alley, Signal Corps Eighth Quarterly Report, Sept. 30, 1957.

2. P. Bender and E. Beaty, Phys. Rev. Letters 1, 311 (1958).


## VI. RADIOASTRONOMY

### A. THE 10 CM MASER FOR RADIOASTRONOMY *
(W. Rose)

A 10 cm maser has been designed and built at Columbia for use on the Naval Research Laboratory 84 foot antenna in Washington D.C. The 80 °K noise figure and 20 Mc bandwidth of the maser-radiometer will enable us to attain an RMS noise fluctuation level of .01 °K when a 10 second time constant is used. With this high sensitivity we expect to make a number of radioastronomical measurements that would be impossible with a conventional receiver. By measuring the equivalent blackbody temperature of Saturn at this frequency we can determine if it has a non-thermal radio spectrum similar to that of Jupiter. Accurate measurements of the polarization of Jupiter's 10 cm radiation will also be possible as well as a systematic attempt to detect new radio sources.

During the last quarter the detailed engineering which was required to mount the maser on the antenna was completed. Before the radiometer could be installed on the radiotelescope a leak and subsequent thermal contact developed in the helium dewar. Although an attempt was made to repair the dewar, it soon became apparent that a new cryostat would be necessary. A new dewar is presently under construction at the Naval Research Laboratory.

## B. M-BAND RADIOTELESCOPE*
(W. Kahan)

NVII hfs line: During the past quarter the M-band radiotelescope was used to search for the NVII hfs emission line in the corona of the sun from 52,975 Mc to 53,080 Mc. A preliminary analysis of the data shows no line that can be discerned in the background system noise. If upon carefuf examination of the data no line is found, then an upper noise limit on the abundance of nitrogen in the sun will be deduced from the data.

A tentative explanation of the "bump" in the data of June 30, which was shown in Fig. 1 on page 8 of the last Quarterly Progress Report, is that the radiometer gain was unstable; it increased then decreased producing the same effect as an emission line. When the antenna pointed into the sky off the sun[1], the antenna temperature was very close to that of the chopper resistance cards used for comparison. Therefore gain fluctuations were not so easily discernable as when the antenna pointed into the sun.

The gain fluctuations stem from variations in efficiency of the IN53 superheterodyning crystals and can be compensated for by changing the gain of the i.f. amplifier in a way that would keep the gain of the system constant. I plan to add a gain stabilizing network to the radiometer during the next interval.

Atmospheric $O_2$ line: When searching for the NVII line in the corona of the sun, the radiometer recorded the spectrum of the telluric molecular oxygen $27^-$ absorption line at 53.07 kMc. The intensity of the absorption was radically different on two different runs, being very pronounced in the run of Sept. 29, 1961 and not detectable in the run of Oct. 11, 1961. Professor C. H. Townes suggested that the change in absorbing intensity may be due to changes in the density of $O_2$ in the high atmosphere which would sharply affect the peak of the $O_2$ line. A more

complete study of the $O_2$ line and its intensity variations will be made during the next quarter.

Program for the next interval: The data of the search for the NVII hfs line as well as the pertinent theoretical calculations will be prepared for a forthcoming progress report.

An automatic gain control system will be added to the radiometer to be used in connection with the study of the 27" telluric $O_2$ line and the correlation if any, which exists between the intensity of the line and upper atmospheric weather.

David L. Carter and I have completed calculations on the shape of the absorption spectrum of $O_2$ in the earth's atmosphere considering the atmosphere to be isothermal and having an exponential decrease of $O_2$ density with altitude. The results of these calculations and their bearing on the study of the $O_2$ line will be discussed in a forthcoming progress report.

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*This research was also supported by the Air Force Office of Scientific Research under Contract AF 49(638)-631.

1. CRL Quarterly Report, Sept. 15, 1961, Fig. 2, p. 8.

## C. MICROWAVE ABSORPTION IN MODEL PLANETARY ATMOSPHERES*

(W. Ho, P. Thaddeus)

An experimental study of the high pressure resonant and non-resonant absorption of microwaves by gases is being undertaken at the Columbia Radiation Laboratory in conjunction with a theoretical investigation of planetary atmospheres, in particular that of Venus, now in progress at the Institute for Space Studies of the National Aeronautics and Space Administration. Unlike most previous investigations, which have aimed at an understanding of the physical mechanism of pressure broadening and non-resonant absorption in single gas species, we are concerned with the study of absorption in model planetary atmospheres composed of various mixtures of simple polar and nonpolar gases, such as water vapor and carbon dioxide.

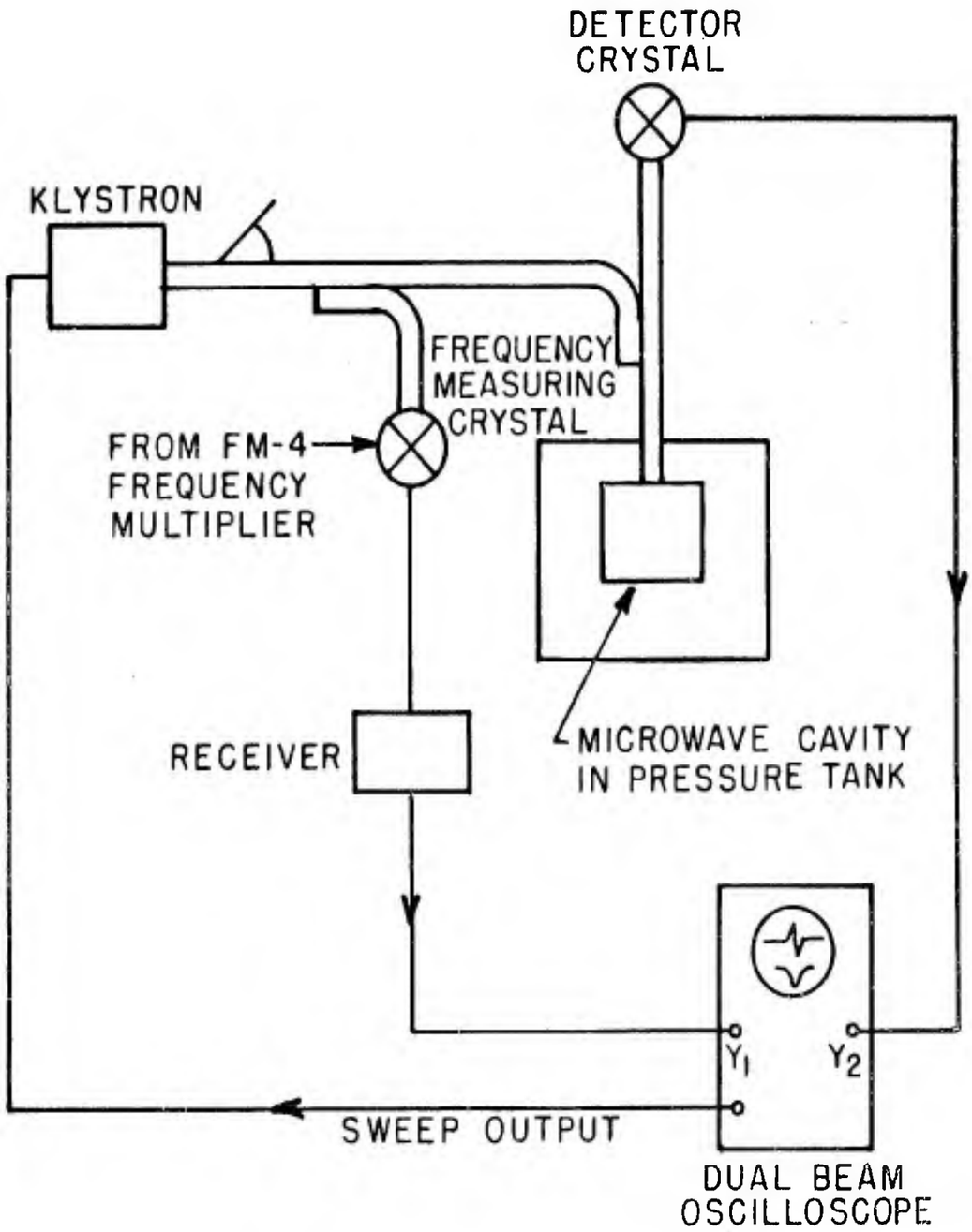


FIGURE 15. Schematic illustration of the high pressure absorption spectrometer.

A number of observations[1] of Venus in the centimeter region during the past six years, among which the work of Giordmaine, Alsop, Townes, and Mayer[2] using a ruby maser constructed in the Radiation Laboratory should be mentioned, have indicated an effective thermal temperature of the planet at this frequency in the vicinity of 585 °K, a very high figure when it is realized that with its high albedo Venus actually absorbs from the sun slightly less energy per unit area than the earth. Attempts to explain this high effective temperature as due to radiation from a dense ionospere, or charged particles in radiation belts about the planet, have been unsuccessful. It is now generally felt that the observed radiation is truly thermal and derives from the surface of the planet itself, or at least from a dense layer of the atmosphere far beneath the upper surface of the clouds. On this assumption, the high observed temperature is attributed to a strong greenhouse effect, an hypothesis made more plausible by the recent indications of water vapor in the Cytherean atmosphere. Recent measurement in the millimeter region, however, have indicated a substantially lower temperature in this frequency region, and it has been realized that a detailed understanding of the radio observations must be based on an analysis of the microwave emissivities of the various atmospheric layers.

The experimental apparatus employed in our initial experiment follows closely the arrangement used by Birnbaum, Maryott, and Wacker[3] for measurements of the non-resonant and microwave absorption by $CO_2$. The absence of sharp resonance lines prohibits the use of the Stark and Zeeman modulation techniques which allow the detection of attenuation constants, $\alpha$, as low as $10^{-9}$ $cm^{-1}$ in conventional microwave spectroscopy. It is feasible, however, to measure $\alpha$'s as low as $10^{-6}$ $cm^{-1}$ by determining the effect of the non-resonant absorption on the quality factor of a microwave cavity. A block diagram of the experimental apparatus is shown in Fig. 15. The response of a high mode cylindrical cavity in one of the parallel plate modes near 20 kMc/sec is observed using a klystron carefully shock mounted and thermally stabilized in an oil bath. The cavity is mounted in a high pressure tank capable of withstanding pressures of up to 20 atmospheres. The cavity response width, and hence its quality factor with and without the addition of a foreign gas is measured with a dual-beam oscilloscope and pips from a communication receiver obtained by beating the klystron against harmonics of the output of a Gertsch FM-4 meter, locked in turn to the Laboratory's frequency standard. No attempt has yet been made to tune the cavity back to its original frequency after the shift produced by the dielectric constant of the foreign gas, although this will be done in later experiments. Further

measurements will also be made with a more stable klystron by observing the change in reflected power produced by the gas at the peak of the cavity response. To date, absorption measurments have been made for pure $CO_2$ at room temperature for pressures from 0 to 200 lbs/in.$^2$ at a frequency near 20 kMc. The results are in agreement with those obtained by Birnbaum, Maryott, and Wacker. We are in the process of converting to a frequency near 9 kMc for measurements on a mixture of $CO_2$ and water vapor at various temperatures.

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*This research was supported also by the Air Force Office of Scientific Research under Contract AF 49(638)-631.

1. Reviewed by C. H. Mayer, "Radio Emission of the Moon and Planets" in Planets and Satellites, ed. G. P. Kuiper (University of Chicago Press, Chicago, 1961) Chap. 12.

2. J. A. Giordmaine, L. E. Alsop, C. H. Townes and C. H. Mayer, Astrophys. J. 64, 332 (1959).

3. G. Birnbaum, A. A. Maryott, and P. F. Wacker, J. Chem. Phys. 22, 1782 (1954).

## D. 6 MM MASER AMPLIFIER*
(D. Carter)

During the last quarter a new 6 mm maser amplifier was constructed. Oscillation but no amplification was achieved. The new design is an attempt to control coupling to the microwave resonances. Some estimates of antenna temperatures for various radio sources were made.

The results of these calculations and results of coupling control experiments will appear in a later progress report.

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*This research is also supported by the Air Force Office of Scientific Research under Contract AF 49(638)-631.

# VII. CRYOGENICS

## A. HIGH FREQUENCY PROPERTIES OF SUPERCONDUCTORS*

(B. Biavati, S. Zemon)

We are attempting to investigate, by means of microwaves, some of the properties of the energy gap in the electronic excitations of superconductors. Specifically, one of these properties is the width of the gap as a function of the temperature. This may be determined through the ratio of the surface resistance of a cavity in the superconducting and in the normal states. This ratio is determined through the measurement of the relative power reflected from the cavity at resonance in the two states. The superconducting metal currently being investigated is high purity, polycrystalline zinc.

A low VSWR waveguide is very important in this experiment because large percentage errors in the measured reflected power from the cavity can occur due to spurious reflections, especially at the top of the waveguide where a .001 in. mylar vacuum seal is placed next to the flange. For example, if P is the power down the guide and a spurious reflection at the top of the guide causes a VSWR of 1.1, then about 1 % of the power is reflected here or P/100. Let us say that the waveguide attenuates the power about 1 db/ft and the cavity absorbs about 3/4 of the incident power. Then for a five foot long guide the reflected power coming out at the top of the guide is about P/40, which is the same order of magnitude as the spurious reflection. Therefore during this quarter extensive work was put into fabrication of a five foot long .015 wall brass RG98 waveguide, with a 90 deg bend, a foot long section milled down to .010 in., two gradual bends to avoid line of sight temperature radiation, and an accurately located flange with an O ring grove on one end. It was found to be very important for the flange to be flat and accurately perpendicular to the waveguide axis. One usually found a VSWR of about 1.1 and sometimes much less over the frequency range.

After the guide was fabricated, a way was sought to cancel out the effects of the remaining spurious reflections. The procedure used was to go to low temperatures in order to pick out the resonant frequencies with which we wished to work, then go back to room temperature, replace the cavity with a matched load, and use a reproducible method for cancelling out the spurious reflections at each of the resonant frequencies. After this, we went again to low temperatures with the cavity, and at each particular frequency reset the necessary microwave compo-

nents to their predetemined values for minimum spurious reflection.

For the matched load we used a device which was made from a piece of lossy reinforced plastic, Emairon# 7033, made available through the courtesy of Electronautics Corporation of Maynard, Mass. The Emairon was machined into the form of a cone with vertex angle of about 6 degrees and a sharp point at the vertex. The other end of the cone was milled to a rectangular cross section so that the whole device could fit snugly into the waveguide. This cone had a VSWR of 1.01 or less over the entire range of 98 guide frequencies.

At first an E-H tuner was placed next to the mylar seal as a way of tuning out the spurious reflections. We found that this tuner was not easily able to be reset because the plungers of the tuner could change their positions slightly relative to the cross section of the waveguide. Also at some frequencies the tuner could not appreciably reduce the VSWR.

Next a method was set up whereby one would take a sampling of the incident power and control its phase with a DeMorney-Bonardi semi-calibrated phase shifter and its amplitude with an FXR precision variable attenuator. This signal was applied to the detecting crystal and its phase and amplitude set so as to buck out the spurius signal at the detector. This method was found to be stable and reproducible. The spurious reflections could be reduced by at least 20 db, leaving a negligible error. The major difficulty in this procedure is the resetting of the klystron frequency during the room temperature measurements.

Once these procedures were established, a new ultra-pure zinc cavity was constructed, soldered together with pure indium and chemically polished. The sample was placed in the helium-3 cryostat and a run at low temperatures was carried out. Because of trouble in maintaining temperature stability in the cryostat, it was decided to take data on the fly. To do this we swept the klystron through one of the cavity resonances with a 250 cps sawtooth. The power reflected from the cavity was amplified and displayed on the y-axis of the oscilloscope while the x-axis was swept with the sawtooth. The preamplifier used was the Tektronix RM 122 with 1.6 cps and 40 kc as the bandpass 3 db points. The crystal detector was the Microwave Associates type MA428, electrically isolated from the rest of the guide. (The crystal detector was found to be square law at low levels to within at least 5 % and its VSWR about 1.08 over a broad range.) The trace of the resonance curve was photographed with the Tektronix C-12 oscilloscope camera with 10,000 speed

polaroid film. In this way pictures could be taken rapidly as the temperature of the zinc sample was varied.

A serious leak developed during this run so only a small amount of preliminary data (uncorrected for spurious absorption) was taken at 57.9 kMc. The data was processed as follows. Measurements were made from the oscilloscope pictures of the relative power, $P/P_0$, absorbed by the cavity at resonance. The distance, h, from the zero power level to the bottom of the resonance curve was measured. Then the trace of the mode curve was estimated as if the resonance were not there and, for the same frequency, the distance H was measured up to the curve from the baseline. H and h were determined by using a low power microscope and a movable microscope stage. Now $P/P_0 = h/H$ so that using VSWR $= (1 + \sqrt{P/P_0})/(1 - \sqrt{P/P_0})$ we have for an undercoupled cavity:

$$Q_{\text{coupling hole}}/Q_{\text{wall}} = \text{VSWR} ,$$

and for an overcoupled cavity:

$$Q_{\text{coupling hole}}/Q_{\text{wall}} = 1/\text{VSWR} .$$

$Q_{\text{wall}} = C/R$ where C depends only on the geometry of the cavity and the frequency and R is the surface resistance. Since $Q_{\text{coupling hole}}$ depends only on the geometry which does not change at very low temperatures, then it is the same in the normal and superconducting states. Thus $(Q_{\text{wall}})_{\text{normal}}/(Q_{\text{wall}})_{\text{superconducting}} = R_{sc}/R_n$ and it is conventional to plot $R_{sc}/R_n$ vs temperature.

Three resonances of practically the same frequency were photographed. One can tell from a plot of the relative surface resistances that the transition temperature of zinc is somewhere between .82 and .83 °K which agrees with the best data[1] on very pure zinc for which $T_c = .825$ °K. The data of each resonance showed about 10 % scatter and each of the three curves showed at worst a 20 % scatter from each other. $R_{sc}/R_n$ was about .2 at a T of about .4 °K. It has not yet been ascertained whether some or all of these results are due to instrument limitations, spurious reflections or imperfect surface conditions of the cavity.

During the run a 10 ohm 1/10 watt Allen-Bradley resistor was used as a secondary thermometer and it was calibrated against the temperature obtained from the vapor pressure of helium-3 using the relations

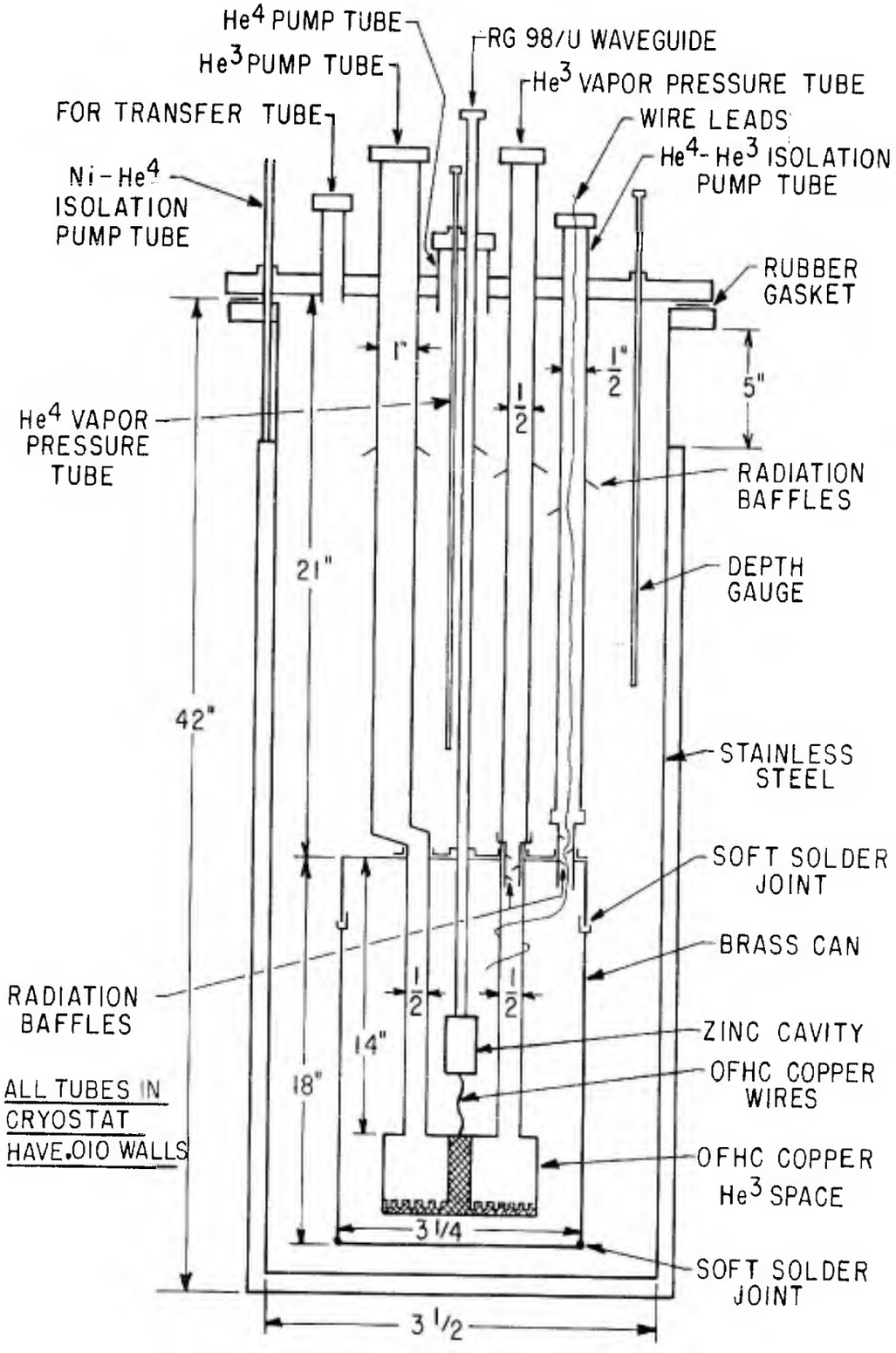


FIGURE 16. Schematic of $He^4$ and $He^3$ spaces.

suggested by Sydoriak and Roberts (corrected for thermomolecular pressure differences when necessary). It was found that measuring currents of 1 $\mu$amp in the resistor could produce noticeable temperature gradients between the resistor and the OFHC copper helium-3 bath space at temperatures of about .31 °K. A current of 1 $\mu$ amp would correspond to a heating of about 2 erg/sec. Lindenfield[2] found somewhat similar results for germanium thermometers above 1 °K. For thermal contact between the resistance thermometer and the copper we used an unbaked solution of G.E. 1202 varnish and # 1500 thinner.

During the calibration care was taken to allow a minimum of helium-3 in the vapor bath and the pumping spaces in order to achieve rapid, reliable results; otherwise troublesome temperature gradients could exist in the liquid helium-3. To help the procedure we went towards temperature equilibrium by warming slightly, to take advantage of the convective heat flow in the liquid in the vapor bath space.

Because of serious drawbacks in the helium-3 cryostat it was apparent that another one had to be built if we were to obtain worthwhile results in this experiment. We used the stainless steel nitrogen dewar from the old cryostat and ordered a liquid helium-4 dewar from Superior Air Products Co. A helium-4 helium-3 isolation space, a helium-3 space, and two pumping stations were constructed in the Physics Department Machine Shop. VIC 2 in. air-cooled diffusion pumps, rated at 150 liters/sec, were used (with water-cooled baffles) to pump on the isolation spaces and the vapor of the liquid helium-3. They were found to be satisfactory. 3/4 in. VIC toggle valves were used and found adequate. However the 2 in. VIC toggle valves could not maintain a vacuum seal against an atmosphere pressure difference. A number of Veeco valves were also used, but instead of soldering to them, flanges were machined onto the brass body and O ring seals were used. Practically all the solder joints were hard soldered to achieve maximum mechanical strength.

This cryostat was tested and worked quite well. Liquid helium-4 could be held for at least 12 hours. Exchange gas was able to be pumped out and good isolation established at 4.20 °K within an 1/2 hour. The lowest temperature reached in the helium-4 space was 1.285 °K and in the helium-3 space, .308 °K. The temperature of .308 °K could be reached in 1/2 hour and with a heat input of .2 mw a temperature of .314 °K could be maintained. A sketch of the isolation and helium-3 spaces is shown in the accompanying figure. It should be noted that it took 45 days from the initial planning to the successful run. We wish to express our thanks to the Physics Department Machine Shop, especially to

Aaron Scheer, John Domanski, and Jim Woods for their excellent work.

Program for the next interval: We plan to make a run with the new cryostat, taking extensive data on zinc as a function of temperature and frequency. We hope to determine the cause of the scatter in $R_{sc}/R_n$ and set up a convenient, accurate method of obtaining and working up of the data. We also hope to find a way to avoid the power dependence in the calibration of the secondary thermometer.

*This research was supported also by the National Science Foundation under Contract NSF-G 17080.

1. Philips, Phys. Rev. Letters 1, 363 (1958).

2. Lindenfield, Rev. Sci. Instr. 32, 9 (1961).

## B. RADIATION PRESSURE OF SECOND SOUND IN LIQUID HELIUM II

(C. Metz)

If periodic thermal pulses are generated in liquid helium II, it has been found that these pulses will be propagated in the liquid just as pressure pulses are propagated in a gas, i.e., in the form of waves. By analogy, these temperature waves in liquid helium II are called "second sound". The present experiment is concerned with the radiation pressure of second sound at lower temperatures than those previously used and also as a function of frequency and intensity of the second sound beam.

The most successful method so far investigated in this experiment of producing thermal pulses in liquid He II has been the application of a sinusoidal alternating emf to a thin gold film evaporated on a glass substrate.

During the last quarter some measurements were made of the radiation pressure vs frequency, intensity of the second sound beam and the temperature of the liquid helium. Exact results could not be calculated due to defects in the voltmeter, signal generator and second sound source. The signal generator and voltmeter have been repaired, the voltmeter recalibrated, and new sources made.

Program for the next quarter: Radiation pressure measurements will be made with several beam intensities in the temperature interval from 1.25 °K to 2.10 °K at frequencies of 15 and 20 kc/sec.

### C. ELECTRONIC AND LATTICE HEAT CAPACITIES OF SUPERCONDUCTORS
(H. Leupold)

Up to the beginning of this quarter 200 measurements of the specific heat of a pure niobium crystal had been made between 1.3 °K and 10 °K. The anomaly of the lattice specific heat in the superconducting state was found to be smaller than that measured in a less perfect sample. During this quarter 200 additional measurements have been made on the inferior specimen to confirm the difference in the magnitudes of the anomaly in the two samples. The data from these measurements are now being processed.

## VIII. MAGNETRONS AND SPECIAL DEVICES

### A. LOW FIELD OPERATION OF MAGNETRONS
(M. J. Bernstein)

One new low field magnetron designed to operate at 2.6 mm (RPB9 Series, 22 vane) has been completed during the past quarter. Cathode emission was quite poor since it was necessary to process the tube several times to achieve vacuum tightness. No oscillations were observed although it was possible to obtain currents up to 5 peak amps at voltages up to 15 kv. After a few hours the emission had deteriorated to a level at which it was no longer possible to obtain anode current.

The investigation of low field magnetron operation at 2.6 mm will be continued.

### B. CRYOGENIC MAGNETS
(H. B. Fleishman, R. Novick)

This is the first report on a new project to construct a high field, superconducting solenoid at the Columbia Radiation Laboratory. The abrupt and total disappearance of electrical resistivity of certain

metals at low temperatures was discovered by H. Kamerlingh Onnes in 1911[1] shortly after he succeeded in liquifying helium. The phenomenon became known as superconductivity.

It was also Onnes who in 1913[2] first suggested the use of superconducting wires for the windings of electromagnets. Initial attempts to build superconducting magnets met with little or no success as it was found that applied magnetic fields greater than a fairly low bulk-critical value restored the electrical resistance characteristics of the metal in the normal state. For this reason it was believed from 1911 to 1955 that superconducting solenoids would be limited to fields of a few thousand gauss. However, in 1955, Yntema[3], using a coil wound with cold worked niobium wire, obtained a field of 7 kgauss. Another advance by Kunzler et al showed that fields of 15 kgauss could be obtained from cold worked molybdenum-rhenium wire. It was apparent, therefore, that by special treatment of some superconductors, namely by bringing more disorder to the structure of the material, fields between one and two order of magnitude greater than the bulk-critical fields could be obtained. It was not until February, 1961 that the possibility of building truly high field superconducting solenoids became highly probable. At that time Kunzler et al[4] reported that a specially fabricated wire, cored with $Nb_3Sn$, remained superconducting in a field of 88 kgauss. Shortly afterwards these same workers reported the alloy of Nb-25 % Zr to have similar high field properties. In May of 1961 there was still no wire of either $Nb_3Sn$ or Nb-Zr available nor had anyone fabricated a coil from these materials. It was decided then that we would attempt to construct a high field magnet in this laboratory.

Some of the advantages of a superconducting magnet over a normal magnet derive from the zero power dissipation in the former compared with the totally wasted Joule heating in the latter. Superconducting magnets also have an advantage when experiments requiring liquid helium temperatures are performed. While a 60 kgauss superconducting coil can consist of a 7 cm diam solenoid, a similar room temperature magnet would require a room in itself plus space for motor generators and water pumps. It therefore seemed both feasible and desirable to attempt to construct a superconducting magnet.

Initially, we attempted to fabricate small wire samples for testing as there were none commercially available. Small samples of stainless steel jacketed $Nb_3Sn$ wire approximately 20 mil in diameter were made. All attempts to fabricate NbZr using the facilities of the Columbia University Metallurgy Dept., whose efforts are greatly appreciated,

met with no success as we could not attain the high temperatures (2200-2500 °C) required. Fortunately, by this time $Nb_3Sn$ wire consisting of an Nb jacket 7.5 mil thick with a core consisting of highly packed $Nb_3Sn$ powder 7.5 mil in diameter became commercially available.

Our first tests were then performed on short lengths of the $Nb_3Sn$ wire in the following manner. The neck of a metal dewar containing a short sample of wire with current leads indium-soldered and mechanically held with screws, was placed in a 17 kgauss field. Potential leads were indium soldered to the sample approximatley 2 cm apart. The potential across the superconductor was measured with a Leeds and Northrup potentiometer and a galvanometer having a sensitivity of .34 $\mu$v/mm deflection. The current supply consisted of four 2 volt submarine batteries connected in series with an appropriate shunt enabling current to be regulated from 0-60 amps. The purpose of the external 17 kgauss field was to quench the superconductivity of the niobium cladding of the wire to insure that any superconducting properties measured would be those of the $Nb_3Sn$ core alone. Prior to testing, the wire was reacted in vacuum at 960 °C for 15 hours. The results of these tests on short lengths of $Nb_3Sn$ wire were consistent with those of Kunzler. 22 amps were passed through the wire before a potential appeared across it. For the 7.5 mil $Nb_3Sn$ core, this corresponds to a current density of approximately 83,000 amp/cm$^2$. Subsequent tests on samples of Nb-Zr wire 20 mil in diameter indicated current densities of at least 30,000 amp/cm$^2$, (the sample was still superconducting at 60 amps), also consistent with the findings of Kunzler et al.

A small coil of $Nb_3Sn$ wire was then wound. Its dimensions are as follows:

winding length = 2 in. ,

core diam = 25 in.,

wire diam = .015 in. ,

no. of turns = 993.

A coil with these properties carrying 20 amps would be expected to produce a field in the core of approximately 5 kgauss. No insulation between windings was used as the coil was placed in a 17 kgauss external magnetic field. This would quench the outer jacket of niobium which in its normal state would act as an insulator between windings. Potential

leads were placed across the windings. The maximum current passed before resistance began to retum was 15 amps corresponding to a field in the magnet of approximately 4 kgauss. The reasons for the wire not carrying the same current, 20 amps, as the short length are not yet understood.

It is now possible to obtain Nb-Zr wire in sufficient quantities and lengths to construct a 50-60 kgauss magnet. The Nb-Zr wire was chosen over the $Nb_3Sn$ wire for various reasons. Although $Nb_3Sn$ wire appears to allow for higher current densities and a higher critical field, its mechanical properties are very poor compared to those of Nb-Zr. The reacted core of $Nb_3Sn$ wire is extremely brittle and the possibility of a uniform continuous core existing in a coil containing thousands of feet of wire cannot be insured with any certainty. Nb-Zr on the other hand is a solid wire whose tensile strength compares with that of high grade steel. We have therefore ordered about 6,000 feet of Nb-Zr wire .010 mil in diameter for the construction of a solenoid designed for a maximum field of 50 kgauss.

Additional evidence of the feasibility of these magnets was presented to the International Conference on High Magnetic Fields held at M.I.T. in November, 1961 in the following reports. Kunzler of Bell Labs reported the operation of a $Nb_3Sn$ solenoid at 67 kgauss. J.K. Hulm of Westinghouse Corp. reported a Nb-Zr magnet with a field of 57 kgauss. S. Autler constructed a Nb3Sn magnet giving 28 kgauss and a Nb-Zr magnet of 30 kgauss.

At the present time we have completed the construction of a glass dewar system and have made initial designs for a 50 kgauss Nb-Zr solenoid. Although there are problems that remain to be solved before a high field superconducting magnet becomes part of the laboratory's magnet facilities, rapid progress in the next quarter is expected.

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1. H. K. Onnes, Commun. Phys. Lab. Univ. Leiden No. 122b (1911).

2. H. K. Onnes, Commun. Phys. Lab. Univ. Leiden No. 133d (1913).

3. G. B. Yntema, Phys. Rev. 98, 1197 (1955).

4. J. E. Kunzler, E. Buehler, F. S. Hsu, and J. H. Wernick, Phys. Rev. Letters 6, 89 (1961).

## C. DETECTION OF CHARGED PARTICLE TRACKS IN A MICROWAVE CAVITY

(M. J. Bernstein, N. M. Kroll, L. M. Lederman, A. Strelzoff)

We have previously reported that when a charged particle passes through a microwave cavity and counter telescope, and a high powered magnetron pulse is fed into the cavity, a discharge is produced.

This discharge generally takes the form of many dots which fill the cavity uniformly. We have been attempting to quench the spreading of the discharge so that a single track will appear along the path of the charged particle. In the past quarter we have used xenon gas and xenon plus water vapor mixtures in an effort to determine the effect that a low ionization potential impurity might have on the spreading of the discharge.

In principle, one might expect little spreading in xenon because it has such a low ionization potential. Any resonant photons coming from highly excited states would be incapable of ionizing any other gas atoms. The discharge, however, was found to spread as much as it had before in neon and argon.

Various mixtures of xenon and water vapor with water vapor pressure from a few microns to about 4 mm Hg in xenon with pressure from 200 to 400 mm Hg were tried. The water has a higher ionization potential then xenon and should not be ionized by any xenon photons, but should absorb some of them. For each mixture of $H_2O$ and xenon the power was varied carefully in the neighborhood of breakdown. It did seem that with a mixture of $H_2O$ with vapor pressure of about one or two mm Hg in xenon with pressure of about 300 mm Hg, the discharge was often confined to about half a dozen dots along a 1-1/2 cm path clustered about a half centimeter radius. The dots were very faint and there were troublesome reflections from the shiny cavity walls, so no clear results can be claimed. We are obtaining a large quartz vessel with opaque back and side walls to help reduce the reflections.

In addition to the work with quenching gases in a "dirty" system we are building an ultrapure gas handling system for high temperature bakeout and gas purification. We hope that ultrapure gas will cure the discharge spreading, but the complexity and expense of the device will be increased considerably if it proves absolutely necessary to operate with ultrapure gas.

## D. UNIVERSAL RESONANCE LAMP*

(A. Gallagher, P. Horwitz, A. Lurio)

This is the first report on a new investigation to develop a universal resonance lamp. The interest in this work lies in the need for a high intensity source of resonance radiation in all research by the methods of optical double resonance, optical pumping, and level crossing. Two principal problems to be overcome in designing a universal lamp to furnish this radiation are (1) the source window must be kept transparent to the desired resonance radiation and (2) self-reversal must be eliminated.

Our approach has been to start with a lamp design which has been developed previously and to improve the design by the application of recent technology and the introduction of small changes.

From a study of the literature on light sources[1,2] it was felt that the Flow or Cario-Lochte-Holtgreven design would be most promising. A lamp of this type has been constructed and a sketch is shown in Fig. 17. The element whose radiation is to be investigated is evaporated from an oven which also serves as the ground electrode of a 60 Mc/sec rf discharge. The hot electrode, as shown, is external to the quartz vacuum jacket. A stream of argon gas is brought in near the lamp window and directed toward the oven to prevent any condensation of atoms on the window. In addition the argon stream starts and maintains the discharge and carries away the unexcited atoms from the region in front of the oven where they could absorb their resonance radiation and self reverse the emission line. The best operation (for thallium) has been obtained by use of a klystron grid (.200 in. diam) for the oven aperture.

Tests of the lamp have been carried out for the thallium ($6p\ ^2P_{1/2} \rightarrow 7s\ ^2P_{1/2}$) 3,776 Å line in two ways: (1) by using Tl absorption cell and (2) by using a Jarrell-Ash Spectrometer. In both cases the flow lamp yielded an intensity of about four times that of the Osram Tl lamp. No self-reversal was noted in the photoelectrically observed spectrometer intensity plots; however, since the resolution of the spectrometer is about 4,000 Mc/sec at this wavelength no definitive statements can be made.

Program for the next quarter: During the next quarter we are planning to test the universal resonance lamp with a Cd radiation source.

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*This work was supported in part by the Air Force Office of Scientific Research under AF-AFOSR-62-65.

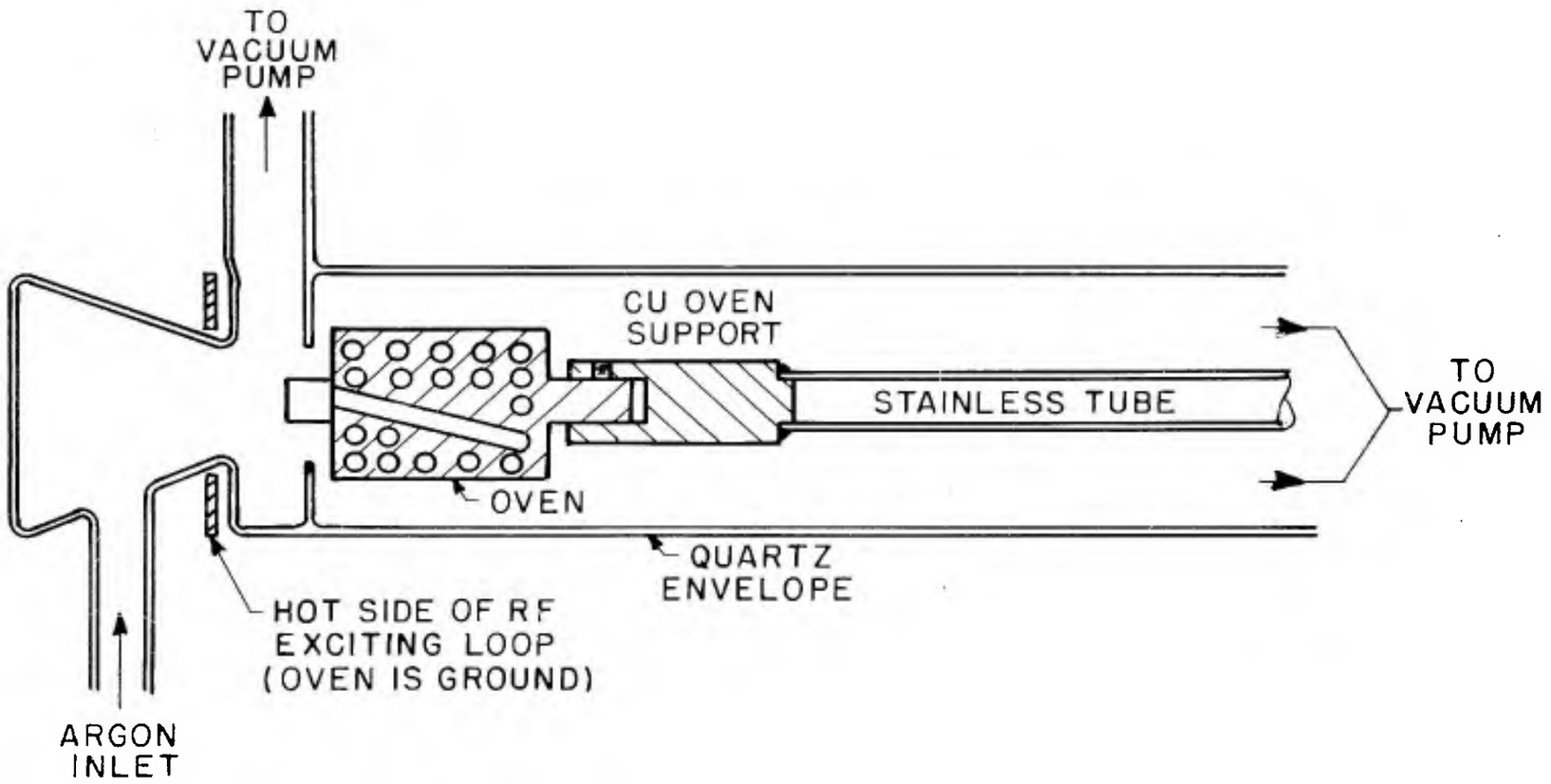


FIGURE 17. Glow discharge lamp.

1. Mitchell and Zemansky, Resonance Radiation and Excited Atoms (Cambridge University Press, Cambridge, England, 1934).

2. S. Tolansky, High Resolution Spectroscopy (Pitman Publishing Co., New York, 1947).

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